V. N. Sokol'skii

RUSSIAN SOLID-FUEL ROCKETS

TRANSLATED FROM RUSSIAN

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(Rakety na tverdom toplive v Rossii)

Edited by S. G. Kozlov

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Chapter I

PYROTECHNIC ROCKETS IN RUSSIA BEFORE THE BEGINNING OF THE 19TH CENTURY

The beginnings of Russian rocketry have not been sufficiently studied, and there are still no accurate data on when rockets were first used in Russia. A number of recently published works on the history of rocketry attempt to date them to the 12th[1], or even the 10th[2] century, but the evidence is unreliable and requires confirmation. In fact, N. G. Chernyshev, who was the first to mention the use of rockets in Russia in the 10th century, wrote in 1949: "It goes without saying that my dating the first use of rockets in Russia to the year 946 is only an initial guess which will require subsequent confirmation by analysis and documentation, especially by materials with which until now nobody has bothered."[3] However, in spite of the fact that more than 10 years have passed since the publication of Chernyshev's work, his guess is still lacking both analytic and documentary confirmation.

The mention in the Ipat'ev Chronicle of the "living fire" used by the Cumans in 1184, which is cited by a number of authors, can also hardly be regarded as proof that rockets were in use in Russia by the 12th century: "The impious and godless and thrice-accursed Konchak had come to Russia with a large party of Polovtsy, intending to capture the Russian towns and burn them with fire for he had found a certain man of Besurmania who shot living fire. Indeed they had taut cross-bows which fifty men could scarcely bend."[4]

Aside from the fact that the chronicle mentions the use of "living fire" not by the Russians, but by their adversaries, one can hardly regard the fact that "living fire" was shot as confirmation of the use of military or incendiary rockets. Most likely what is meant is not rockets, but flame-throwing devices (fiery arrows or missiles with an incendiary mixture) which at that time were widely used in the East and are described in a number of sources.[5]

It seems more likely that the first use of rockets in Russia occurred at a much later period, and was connected with the appearance of gunpowder. The history of rocketry in other countries substantiates this idea.

Although many works on the history of rocketry imply that rockets were known long before our time,[6] none of their claims can be regarded as reliable, the more so in that none of the authors chooses to reveal the sources of his information.

A serious deficiency of these works is that they consider the use of rockets as a subject apart from the general history of engineering and do not connect it with the knowledge of explosives at a given period.

More worthy of attention are the works based on the study of primary sources, which see a connection between the building of rockets and other pyrotechnic devices and the invention of gunpowder.

In Russia powder was first used for military purposes in the second half of the 14th century. There is a wide and rather controversial literature on the date when firearms were first used.[7-18] However, while disagreeing about the precise date, almost all the researchers have concluded that Russian troops became familiar with firearms in the 1370's, and themselves began to use them in the 1380's. Subsequently (in the 15th and 16th centuries) the production and use of powder in Russia steadily increased, as frequent citations of chronicles and other literary sources testify.[19]

There is therefore a basis for supposing that pyrotechnic rockets might have been used in Russia as early as the 15th and 16th centuries, especially since they achieved comparatively widespread use in western European countries at that time, and were described in a number of printed works.[20] However, no documentary evidence of any kind for the production of fireworks in Russia at this period has yet been found.[21] Some historians simply remark that rockets were not used at all in Russia before the time of Peter the Great.[22]

This is surprising, since it is hard to understand why pyrotechnic devices would not have been built in Russia between the 15th and 17th centuries, when all the necessary prerequisites existed. The restraining influence of religion, and fear of causing fires, which were a terrible source of catastrophe in Russia before the time of Peter the Great, are not to be excluded. In any case, the use of rockets in this period remains unclear and requires further study.

The first reliable information on the use of rockets in Russia is from the second half of the 17th century. In 1675 a "firework" display held in the town of Ustyuga made a great impression on all who witnessed it. "Several rockets and firecrackers were set off, and in addition a hundred tarred barrels were set on fire whole before a vast concourse who gathered for this rare spectacle. Even peasants from the neighboring villages gathered on the river bank, but they took the rockets to be a fiery dragon, and fled with fright."[23]

When and by whom these rockets were made can be learned from the book describing the embassy of Klenk in Russia,[24] whose author Balthasar Koiet was in the ambassador's suite.

"On the morning of Thursday, 14 November," Koiet wrote, "after fully two weeks had been spent on the preparation of joyous celebrations of His Highness' birth, in the building where the Russians who had worked on the rockets and already delivered most of them were keeping the remainder in readiness, a spark from the fire — instead of candles, they used certain torches for illumination while working — fell into the powder. A tremendous flame shot forth, and nearly burned the whole building down, injuring five people, one, who received three extensive burns on the neck, seriously. The Russians kept this occurrence secret; if the governor had found out about it, it would have gone badly for them."[25]

Koiet's description clearly shows that Russian experts participated in the preparation of the fireworks. It may thus be regarded as firmly established that at least by the 70's of the 17th century Russian technicians knew the secret of producing pyrotechnic rockets.

In the 1680's a special plant for the manufacture of pyrotechnic rockets was established in Moscow. The exact date of its foundation is still unknown, and although most writers date the beginning of its operations to 1680,[26] there is still absolutely no documentary supporting evidence.

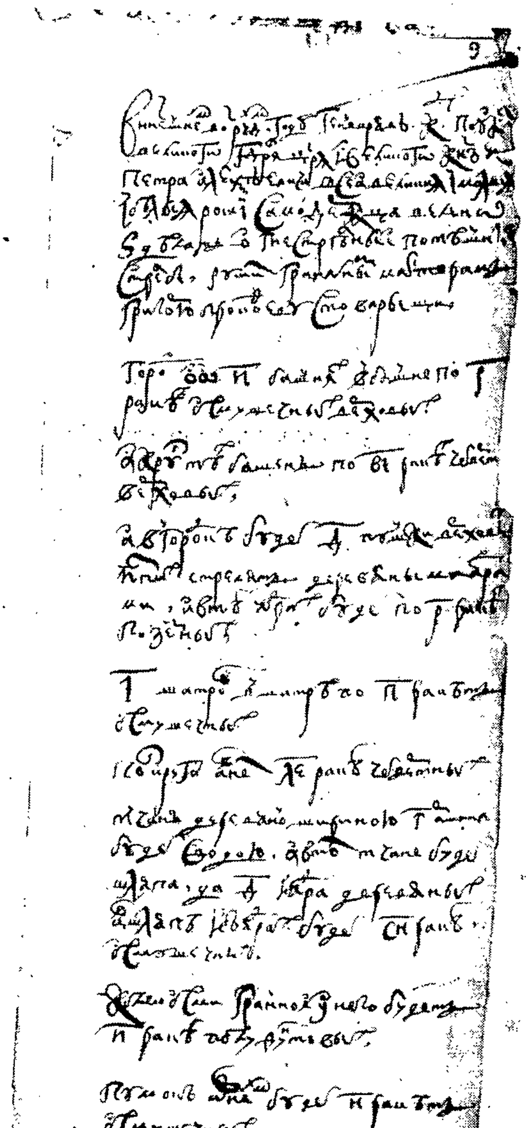


FIGURE 1. Photocopy of the description of the fireworks of 1686 (published for the first time).

In January 1686 Peter I ordered a group of explosives experts to arrange a fireworks display, or, as it was then called, a "fiery entertainment," in the palace.[27] Figure 1 shows the beginning of the decree, which is evidently the first detailed description of a fireworks display arranged by Russian pyrotechnic experts to have come down to us.

In August of the same year, Grigorii Prokof'ev, Andrei Onufriev, and Maksim Klimov, all explosives experts, were ordered to make 2000 eighth-sized rockets, also for a fireworks display.[28]

At the end of the 17th and beginning of the 18th centuries the development of rocketry in Russia was fostered by Peter I, who encouraged fireworks displays and personally took part in the preparation of several of them. In February, 1690, for example, in the village of Voskresensk on the Presna, near Moscow, two such displays were held consecutively. General Patrick Gordon, one of Peter's closest associates, testifies that the Tsar himself participated in the preparation of the second display, which lasted three hours and was a great success.[29] According to Gordon, fireworks were held annually near Moscow, over the four years 1690—1693.[30] Other fireworks displays are known to have occurred in 1696, 1697, and 1699, but the most famous are those of the beginning of the 18th century in honor of Peter's military victories, which are described in the "Book of Mars."[31]

Peter I made the greatest possible efforts to familiarize himself with the latest achievements of science and engineering, and with the successes attained in the most advanced western European countries. With this object he had translated into Russian many foreign books, including a number of works on artillery and pyrotechnics. In 1685, for example, a manuscript translation was made of Joseph-Boilot Langrini's book, "The Arts of Pyrotechnic Weapons and Other Military Ordnance,"[32] which, inter alia, contained brief descriptions of rockets.

In 1694 the book "The Art of Firearms, or Artistic Applications of Fire,"[33] which also contained information about pyrotechnic rockets, was translated from Dutch.

Several other manuscript translations of non-Russian military books which contained quite detailed information about pyrotechnic rockets appeared towards the beginning of the 18th century.

One should also recall the manuscript translations, kept in Peter I's private library, of such books as "A Description of the Art of Artillery, Both Military and for Entertainment,"[34] "The Well-Known Description, Chosen from the Best Authors or Designers, of How to Combine the Various Ingredients for Fireworks Both for Military Purposes and for Purposes of Entertainment,"[35] etc.

Among these translations the most interesting is Georg Andrew Böckler's book, "Manual of Military Architecture,"[36] a manuscript translation of which was also to be found in Peter I's private library.

Of course the sections of Böckler's book dealing with the manufacture and application of rockets were not original. The author himself noted this in the introduction to the second section of the fourth part of his book, where he wrote: "Although various of the older and modern armorers have written a great deal about the classification and depiction of rocket devices, they do not agree, and here their opinions are deliberately bypassed and ignored. Whoever is interested in them should read Schmidlapp, Brechtel, Adrian Romon, Wallhausen, Furtenbuch, Fronsperger,

Schreiber, and many others. Here I wish only to examine, as described above, the latest discoveries and sound foundation for the depiction and classification of rocket devices given by the highly ingenious and elect Lithuanian Lord Casimir Siemienowicz (which I have translated from Latin into German for the delectation of those delighting in such matters), together with other ingenious forms of fire."[37]

The above makes it clear that this manuscript translation was essentially the first Russian version of sections of Siemienowicz's book "The Great Art of Artillery."[38]

This is of considerable interest, since until now translations of Siemienowicz's book were known only in French (1651), German (1676), Dutch (1729), and English (1729),[39] and the fact that the contents of the third section, dealing with a different type of rocket, had been made available in Russian at the beginning of the 18th century, was unknown. Furthermore, familiarity with Böckler's book shows that Siemienowicz's views on rockets were first made available in German not in 1676, as Subotowicz writes, but in 1660, or at the latest in 1672.

In the fourth part of Böckler's book, entitled "Fiery Projectiles for Entertainment," information of great interest about pyrotechnic rockets was given. In particular, a description was given of multistage rockets (which in the Russian translation are called "rockets emerging from rockets"), rocket clusters, rockets with delta-shaped wings, and a number of other exceedingly curious pyrotechnic rockets, illustrated in Figures 2 and 3.

All of the translations mentioned above, as indeed the majority of other translations of the end of the 17th and beginning of the 18th centuries, were not published and remained accessible only to a small circle of people close to Peter I. During the first decade of the 18th century, however, a number of translated works on artillery, in which some aspects of the production and application of pyrotechnic rockets were also dealt with, were published. Among these are E. Brown's book "Modern Theory and Practice of Artillery" (1709),[40] and J. Z. Buchner's "Artillery Study and Practice" (1711).[41]

After the beginning of the 18th century the production of pyrotechnic rockets in Russia grew steadily greater. While rocket manufacture continued in Moscow, the first steps were taken to begin production in Petersburg, too.

A special laboratory for the preparation of fireworks, which is particularly mentioned in his book by the Danish envoy Just Jull, was set up in Petersburg during the first decade of the 18th century. "But shortly thereafter," Jull wrote in 1709, "the laboratory, which was opposite the house of Vice-Admiral Kreits, caught fire. They were working on some fireworks to be set off that very evening . . . There is no doubt that if the fire had lasted a few minutes longer, the laboratory would have exploded and the wooden house where accommodation had been secured for me would certainly have burned down."[42]

As the documents preserved in the Historical Artillery Museum show, the Petersburg laboratory for firework manufacture was first located in Kronverk,[43] but it was subsequently decided to build a new "laboratory building" (pyrotechnic laboratory) in Moskovskaya district.[44]

Construction of the laboratory was completed during the first half of the 1730's.[45] As Bogdanov noted, "an Artillery Laboratory, where pyrotechnic devices and other artillery projectiles are made, was built in 1734 in Moskovskaya district on Liteinaya Street, not far from the arsenal."[46]

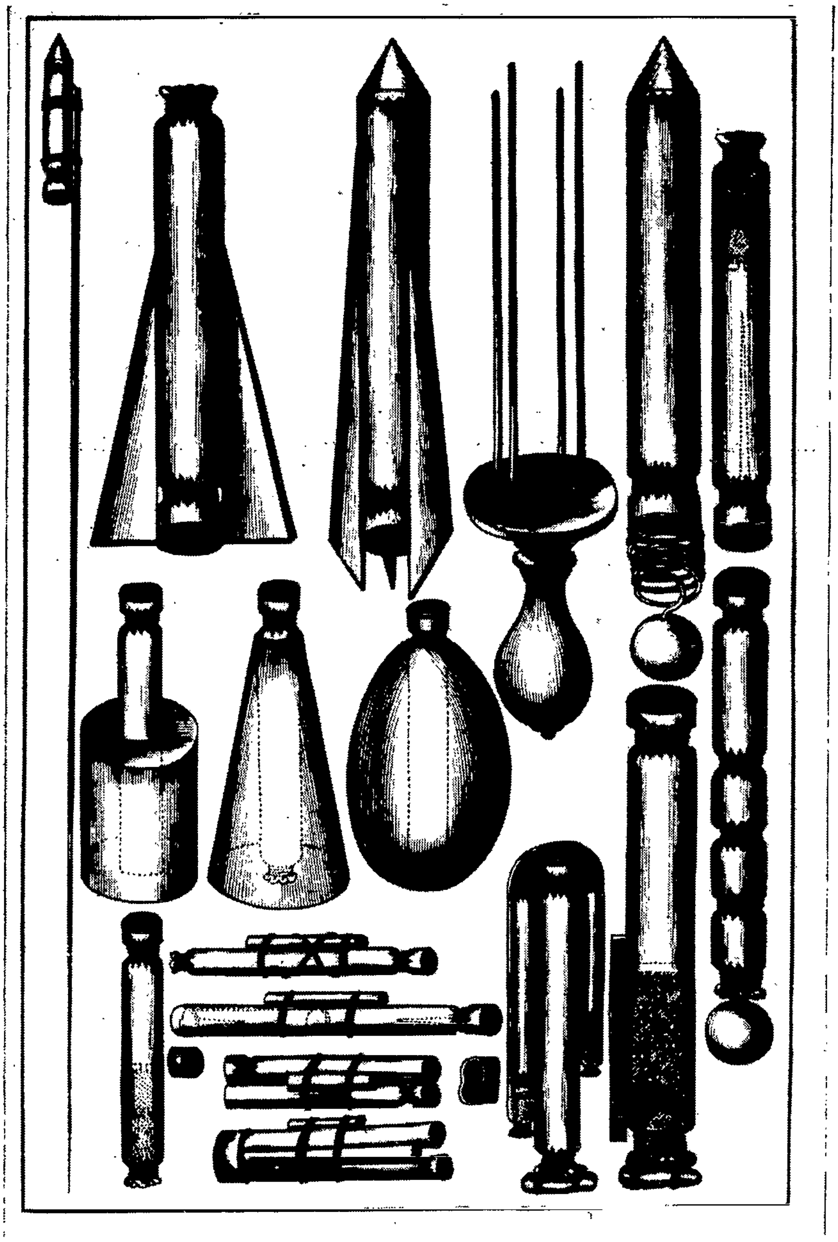
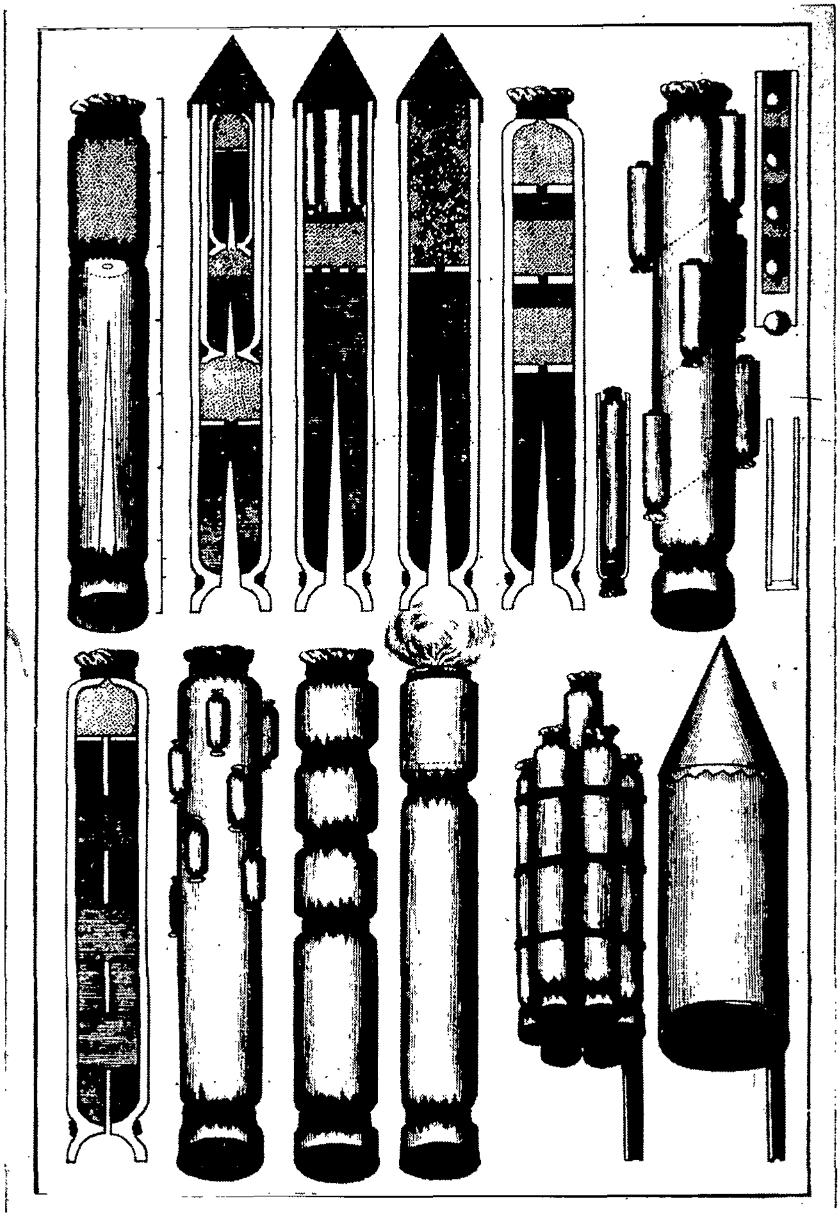


FIGURE 2—3. Pyrotechnic rockets described in G. A. Böckler's book "Manual of Military Architecture"



(the illustrations are from C. Siemienowicz's book "The Great Art of Artillery").

Unfortunately we still possess no sketches or descriptions of the rockets made in Russia at the end of the 17th and in the first half of the 18th centuries, but they can be assumed to have closely resembled those described in the manuscript works in Peter I's private library, as well as in the translations published in Russia at the beginning of the 18th century.

The first descriptions of rockets manufactured in Russia which have come down to us belong to the second half of the 18th century and are given in the books of M. V. Danilov,[47] which were the first original works in Russia to give information on the production of pyrotechnic and signal rockets (see Appendix 2, pp. 169—170).

The rockets manufactured in Russia during these years ranged from 1 1/2 ounces to 24 lb and more.[48] The designations of rockets, however, (1 1/2-ounce, 6-lb, etc.), did not correspond to their actual weight. For example, a 1-lb rocket weighed 12 ounces without tail and 2 lb 2 1/2 ounces with tail.[49] As E. Kh. Vessel' (1799—1853), Professor of Artillery at the Mikhailovskii Artillery College, later explained, "Our rockets are named for the Artillery Weight of the lead balls equal in diameter to their calibers, so that a rocket whose caliber equals the diameter of a one-pound Artillery Weight lead ball is called a one-pounder [etc.]."[50]

The rockets of this period (Figure 4) were quite primitive from an engineering viewpoint, and their quality was very much dependent on the experience and skill of their builders. The so-called high-flying rockets,

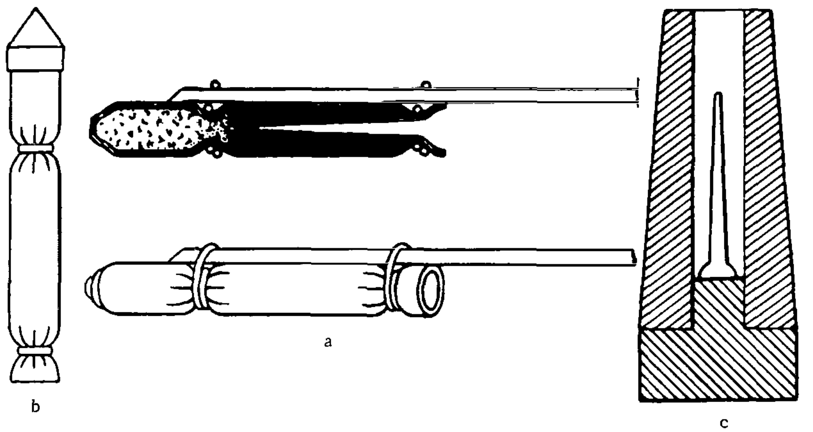


FIGURE 4. 18th-century pyrotechnic rockets.

a — general view and cross section of a rocket with missible; b — rocket casing with cap. c — mold for packing rocket casings (hollow molding).

designed for fireworks and to give signals, were the most widespread type, though "land" and "water" rockets, as well as "Schwärmer," were also in use.

The rockets of the end of the 18th century consisted of thick-walled paper casings into which the powder was stuffed. The pyrotechnic experts then working to improve rockets devoted special attention to the rocket

mixture, since they regarded its composition as to a great extent determining the quality of pyrotechnic rockets. A great many different formulas for compounding the mixture[51] were developed, but basically they all consisted of sulfur, nitrates, and carbon in varying proportions (Table 1).

TABLE 1. Rocket mixture composition
(end of 18th — beginning of 19th centuries)

Serial number	Sulfur	Nitrate	Carbon	Powder pulp
	Parts by weight			
According to M. Danilov				
1	1	2	—	3
2	$6\frac{1}{2}$	32	14	—
3	2	8	4	12
4	4	18	6	—
According to A. Demidov				
1	—	16	7	16
2	—	24	11	24
3	1	5	6	32
4	3	17	7	20
According to A. Markevich				
1	2	8	2,5	—
2	—	8	3.5	8
3	—	4	1.875	4
4	1.5	13	5.25	15
According to F. Cheleev				
1	5	10	3.5	—
2	4.5	9	3	—
3	3.5	12	3.5	—
4	2.25	12	3.5	—
5	0.25	2.25	1.25	2
6	0.25	3	2.25	4
7	2	8	2.67	—
8	—	8	3.5	8
9	—	4	1.875	4
10	1.5	13.5	5.25	16

In spite of the many recipes for rocket compound, however, no attempts were made at scientific development of the results obtained. All of the formulas were empirically chosen and were unsupported by theory. The properties of different explosive mixtures were not even compared, and writers proposing one compound or another gave no indication of its advantages and deficiencies. Each rocket-builder, therefore, generally chose his propellant on the basis of his personal experience.

The rocket casings were made of high-quality heavy wrapping paper, and were equal in length to 7 times the rocket caliber, while the thickness of their walls was 1/7 of the rocket caliber. A cord was tied tightly around one end of the casing, leaving a hole for the escape of the gases formed by combustion of the propellant. The rocket casings were then placed vertically in a specially prepared hollow mold for stuffing. Two-thirds of

the length of the casing were occupied by the propellant intended to provide the propulsive force. Since the force depended on the uniformity and density of the compound, the casing was stuffed in small installments, so that the number and force of the packing blows could be strictly regulated in accord with the caliber of the rocket and the place of the particular fill in the series.

A conical void was left in the propellant at the same end as the exhaust hole, to increase the surface of combustion and consequently the amount of gases formed in the first moment of combustion. Between the ignition channel and the pyrotechnic charge was a layer of propellant of thickness equal to 1 or 1.5 times the caliber of the rocket — the so-called blind propellant, which took practically no part in creation of the propulsive force and served primarily to obstruct the path of the gases formed by combustion of the propellant around the ignition channel.

The remaining third of the rocket casing was filled, depending on the purpose for which the rocket was intended, with dross, shot, or another pyrotechnic substance. After this the upper part of the casing was tightly closed by a cord and glued. The tail designed to stabilize the rocket in flight was a wooden pole attached to the lower part of the casing on one side. There were two coupling points, one at the lower end of the casing, and the other 2/3 of the way towards the other end. The tail was about 7.5 – 8 times the circumference of the rocket in length, and its maximum thickness (near the casing) was 1/3 of the rocket caliber. The finished rocket is shown in Figure 4a.

During the 18th century pyrotechnic rockets became a familiar sight at various celebrations and festivities.[52] Fireworks were held in honor of military victories, commemorative dates, to celebrate the New Year, etc. In addition to the official government fireworks, individuals organized their own small private displays.

Fireworks were produced on an increasingly greater scale, and their preparation sometimes involved the employment of hundreds of people for an extended period of time. The rockets launched at illuminations were numbered in thousands. At the beginning of the 1730's, on Vasil'evskii Ostrov [Vasil'evskii Island, a district of Petersburg], opposite the Winter Palace, a special "fireworks theater, "[53] which consisted of extensive scaffolding mounted on 1000 piles, was built.

The fireworks of this period were a bright, colorful sight. The various allegorical representations which were an integral part of most of the big displays (Figures 5 and 6) in the days of Peter I and his successors were especially striking.

For example, the fireworks display held in Moscow to celebrate the New Year 1710 made a great impression on all who witnessed it. The English and Danish ambassadors, Charles Whitworth and Just Jull, were particularly impressed by an allegory which began with two crowned columns picked out in blue, green, and pale yellow light, between which stalked a burning lion, representing the Swedish army. The lion first touched one of the columns (allegorically, Poland), which thereupon broke from its pedestal and tipped over, then passed to the other column (Russia), which also shook as if about to fall. Then out of a burning eagle, which seemed to soar aloft with outstretched wings (the Russian army), shot a rocket which struck the lion and set it afire, after which it flew into pieces and disappeared. The column, which represented the Russian government, continued to stand unshakeably.[54]

FIGURE 5. Fireworks in honor of the victory over the Swedish fleet near Grantham Island, in 1720.

The fireworks display which ushered in the year 1712 in Petersburg was no less interesting, and is described in a printed pamphlet, a copy of which is preserved in the Central Government Archive of Ancient Deeds.[55]

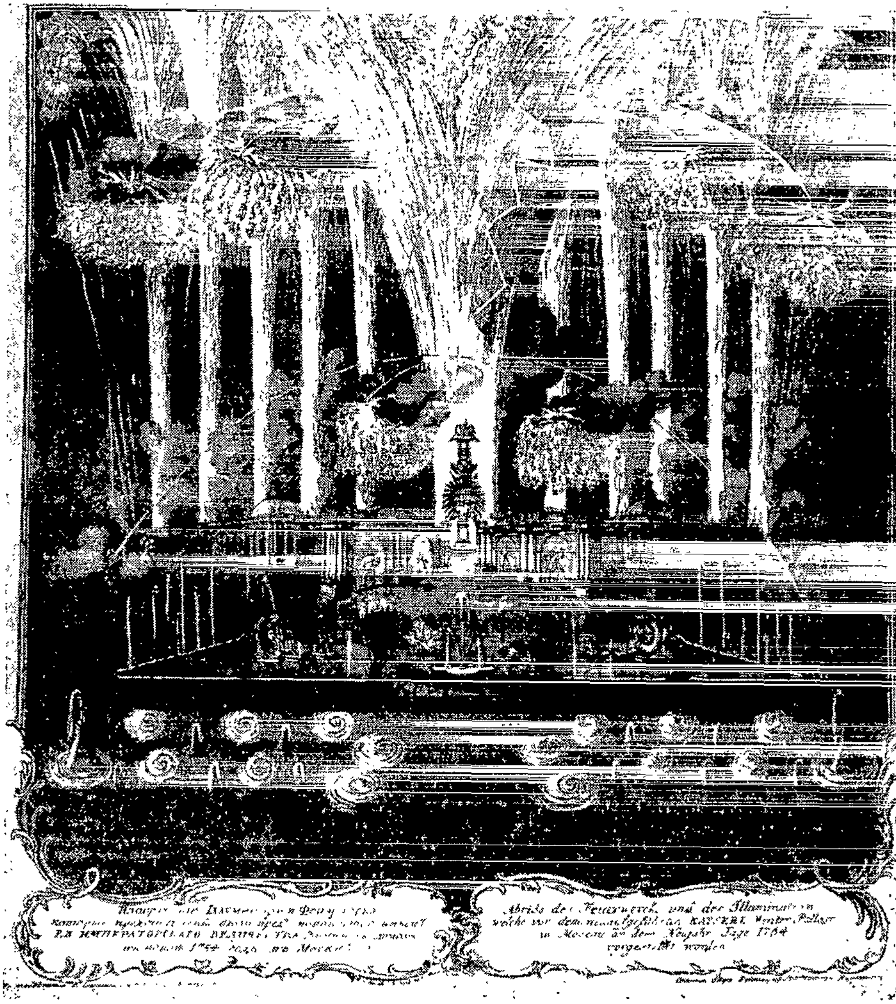


FIGURE 6. Illuminations and fireworks designed by M. V. Lomonosov, held in Moscow in 1754.

The fireworks appeared against the background of a triple triumphal arch with twisted pillars decorated with olive branches. First there appeared on the pediment the image of a laurel-crowned warrior seated on a horse. In his right hand he held a sword, and in his left, an olive branch. Then two figures, symbolizing the union of Europe and Asia,

appeared beneath the pediment. At their feet were depicted various mathematical instruments and commercial wares, together with a serpent coiled around three crowns.

To the right of the pediment appeared Ceres, the goddess of fertility, with a horn of plenty, while on her left was a figure symbolizing truth, with a cross in its right hand, and a palm branch in its left. Implements of war lay at its feet.

These scenes then gave way to others. Between stars and a half moon a dark cloud ascended. This was soon revealed to be an eagle soaring in the sky, and holding in its claws a weapon whose point was aimed at a lion beneath it, etc. The fireworks display concluded with an image of a naval fort (symbolizing Sankt-Petersburg) and a ship coming into port under full sail.

This display was also highly thought of by foreign diplomats and soldiers. As Rasmus Erebo, secretary of the Danish ambassador, noted, the Swedish generals and officers "as well as the ambassador Jull had to admit that it was far more splendid and magnificent than the much-touted splendor of the London fireworks which they had seen, and which had cost £70,000."[56]

Peter I's love for magnificent celebrations and entertainments was inherited by his successors, under whom various fireworks and illuminations were systematically held throughout the second third of the 18th century. Among these the display of April 1742, in honor of Elizabeth Petrovna's coronation, on which the unusually large sum of 19,000 roubles was spent, and the fireworks which greeted the New Year 1756, deserve special mention.

Fireworks became even more common in the second half of the 18th century, under Catherine II, when they took place almost every year and were always marked by great splendor. Occasionally the number of rockets set off during a celebration reached tens of thousands. In September 1793, for example, during the fireworks to celebrate the signing of peace with Turkey, no fewer than 30,000 rockets were launched simultaneously.[57]

There are records of fireworks held during this period in other cities, as well as in Sankt-Petersburg and Moscow, e.g., in Yaroslavl' (May 1767), Kazan' (May 1767), Yamburg (July 1770), and Poltava (June 1772).[58]

Several experts in pyrotechnics regard their gracefulness of form and line as the predominant characteristic of the fireworks of this period. In addition, miniature fireworks, which were held in gardens and parks, and even indoors, became quite popular towards the end of the 18th century.

The expansion of rocket production necessitated a corresponding increase in the number of persons familiar with the technology of their manufacture. Peter I initiated the establishment of a corps of pyrotechnic masters. The explosives experts who participated in the preparation of fireworks in the 1680's have already been mentioned. After the end of the 17th century rocket production became the concern of the officers of the company of bombadiers of the Preobrazhenskii Regiment, among whom the best known were V. D. Korchmin and G. G. Skornyakov-Pisarev. The notes they compiled on rocket production were used by the pyrotechnics experts of subsequent generations for many years.[59]

One might name several others involved in the organization of fireworks in Russia during the first third of the 18th century, e. g., General of the Ordnance Bryus, Corporal Inekhov, Professor Benkenshtein, Colonel Garber, etc.

After the end of the 1730's the programming of fireworks and illuminations was taken over by Ya. Ya. Shtelin (1709—1785). In the 1750's M. V. Lomonosov also took part in their development.[60]

One should also recall M. Danilov, I. Elagin, V. Klement'ev, M. Martynov, P. Melissino, M. Nemov and many other pyrotechnics experts and fireworks designers, who, although many of them remained obscure, all contributed in one way or another to the development of pyrotechnics in Russia.[61]

At the end of the 18th century, curiously enough, the renowned Russian inventor I. P. Kulibin (1735—1818) took an interest in fireworks and illuminations, but he devoted most of his attention not to gunpowder rockets, but to the luminous effects which could be attained by the use of mechanical devices and optical instruments.[62]

By the beginning of the 19th century Russian pyrotechnicians had accumulated considerable experience in the production and application of rockets. Efficient ratios and dimensions for the rocket casing and tail had been developed, the components of the rocket mixture and density of fill had been determined, and the significance of the dimensions and form of the ignition channel were understood.

This experience was reflected in the works on artillery and pyrotechnics published in Russia in the first quarter of the 19th century. The books of A. Markevich, "A Guide to the Art of Artillery" (Rukovodstvo k artilleriiskomu iskusstvu), 1820, A. P. Demidov "Scaffolding and Firework Casings with a Note on the Arrangement of Firework Divertissements" (O stellazhakh, feierverochnykh korpusakh i nechto o raspolozhenii uveselitel'nykh ognei), 1820, "The Composition of Firework Divertissements" (O sostavakh uveselitel'nykh ognei), 1821, "The Origin of Firework Divertissements, the Invention of Powder, and a Schematic Description of Rocket Clusters" (O proiskhozhdenii uveselitel'nykh ognei, izobretenii porokha i skhematicheskoe opisanie raketnykh pavil'onov), 1820, etc., are deserving of mention.

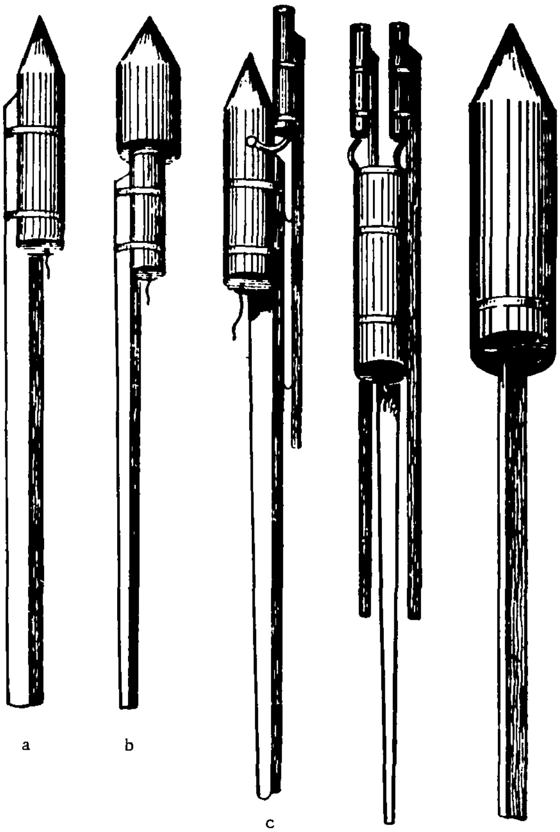
F. S. Cheleev's book "Full and Detailed Instructions for Creating the Entertaining Illuminations Known as Fireworks" (Polnoe i podrobnoe nastavlenie o sostavlenii uveselitel'nykh ognei feierverkami imenuemykh), 1824, is of the greatest interest. This work, written by one of the greatest experts on the art of fireworks at the turn of the 19th century, was a sort of summary of the many years of experience of the Sankt-Petersburg Artillery Laboratory in the preparation of fireworks.

Cheleev's book is in five parts, the first of which discusses the instruments and materials used in pyrotechnics, as well as methods for their manufacture. The second presents the technological process of producing pyrotechnic rockets and gives a description of various high-flying rockets, while the third describes the complicated firework figures produced by burning on the earth's surface. The fourth considers water rockets and indoor fireworks, while the fifth briefly discusses military pyrotechnics.

Cheleev's work contains a number of interesting ideas which show his correct understanding of the fundamentals of pyrotechnic rocket design.

In the introduction to the book, for example, he wrote:

"It is supposed that all the grace of high-flying rockets (Figure 7a, and b) depends on the proportion in which the combustible substances are combined, without going into the proportion of the other parts, which in general make



a b c d e

FIGURE 7. Pyrotechnic rockets at the beginning of the 19th century.

up the rocket, and which include the casing (a roll of paper), into which the propellant is packed; a channel in the propellant, without which the rocket cannot rise; and a wooden tail (a long four-sided bar), without which it cannot rise along the vertical. These parts also have their subdivisions, as follows: the casing can be broken down into the length, thickness, and density of its walls, and the air surface it occupies in space; the channel, into its length, width, and surface which receives its form from the shape of the ramrod; the tail, into its length, thickness, and weight. The quality of the rocket depends on the proportion of these parts."[63]

In discussing the composition of the rocket mixture, Cheleev proposed the following formula, developed from numerous experiments: 75 % nitrates, 10% sulfur, and 15% carbonaceous products. He added that an increase in the percentage of nitrates decreases the power of the propellant, while it is increased by an increase in the percentage of sulfur and carbon.[64]

The book also gives attention to the density of packing of the rocket mixture and the dimensions of the ignition channel. Cheleev wrote that with increase in the density of packing the power of the propellant is decreased, and added: "A further observation must be made about the magnitude of the channel inside the propellant, for the longer and larger it is, the more the propellant flames up, and the greater the stress forces which must be sustained by the walls of the casing."[65]

Cheleev's descriptions of complex and staged rockets are also of interest. In the section on "Rockets with rockets issuing from them," he wrote:

"After inserting into the rear end of the tail of a one-pound rocket two iron brackets, packed in with dross or shot, one an arshin [28 inches] lower than the other, a 1 1/2-ounce rocket can be installed on them with its narrow part placed on the tail of the larger rocket (Figure 7c, and d). Then, moving downwards along the blind propellant a distance equal to 1/8 caliber away from the dross of the pounder rocket, a hole should be drilled through the thickness of the casing to the propellant itself. Into this hole is inserted one end of a small duct used to connect the big rocket with the 1 1/2-ounce rocket, into whose channel its other end is inserted. When the pounder rocket, ignited upon launching, reaches the appropriate height, its blank propellant will have been consumed as far as the hole, and will ignite the 1 1/2-ounce rocket, which will then fly upwards, as if emerging from the larger rocket."[66]

This is evidently an exposition of the working principle of a two-stage gunpowder rocket.

Cheleev also gives a description of rocket clusters. "A bundle of six or more rockets can be made by wrapping them round with a double layer of heavy paper and covering them with a pointed paper cap (Figure 7e). A wooden tail 1 1/4 times the normal length of a tail for a rocket of this caliber, but six times as heavy, and therefore as thick, as normal, is attached in the center of the rocket cluster. The rockets rising into the air will then make a flaming pillar."[67]

Cheleev's book testifies, as remarked above, to the great experience of Russian pyrotechnics experts, although all of their successes were obtained empirically and based on purely experimental, rather than theoretical foundations. By the beginning of the 19th century there were still no theories either of explosive compounds, or of rocket design and flight.

This is to be explained to a great degree by the fact that in Russia, as in other European countries, before the end of the 18th century, rockets were used only for fireworks displays or signalling. The demands made upon rockets for these purposes were not very great. The results obtained through the numerous experiments of the pyrotechnicians were adequate, and no special need was felt for the development of theoretical foundations for rocketry.

At the end of the 18th century in India, and early in the 19th century in Europe, however, rockets began to find military application, and this resulted in increased attention to their quality and presented the experts who built them with new demands.

NOTES

[1] S h u v a e v , N. A. Istoriko-kriticheskii analiz razvitiya osnov mekhaniki peremennoi massy (A Historico-Critical Analysis of the Development of the Fundamental Mechanics of a Variable Mass). Dissertation, p.12. — Gorki State University, 1955.

[2] C h e r n y s h e v , N. G. Problema mezhplanetnykh soobshchenii v rabotakh K. E. Tsiolkovskogo i drugikh otechestvennykh uchenykh (The Problem of Space Travel in the Works of K. E. Tsiolkovskii and Other Russian Scientists), p. 17. Moskva, 1953; T i k h o n r a v o v , M. K. and B. V. L y a p u n o v . Raketa (Rockets). — BSE, 2nd edition, Vol. 35, p. 665.

[3] C h e r n y s h e v , N. G. Rol' russkoi nauchno-tekhnicheskoi mysli v razrabotke osnov reaktivnogo letaniya (The Role of Russian Science and Engineering in the Development of the Fundamentals of Jet Flight), p. 23. — MVTU, 1949.

[4] Polnoe sobranie russkikh letopisei (Complete Collection of Russian Chronicles), Vol. II (Ipat'ev Chronicle), p. 128. SPb. 1843.

[5] For more details of flame-throwers, see F e d o r o v , V. G. K voprosu o date poyavleniya artillerii na Rusi (On Dating the Appearance of Artillery in Russia), pp. 28 — 66. Moskva, 1949.

[6] R y n i n , N. A. Rakety i dvigateli pryamoi reaktsii (istoriya, teoriya i tekhnika) (Rockets and Ram-Jet Engines (History, Theory, and Engineering)), p. 10, Leningrad, 1929; P r i m e n k o , A. E. Reaktivnye dvigateli, ikh razvitie i primenenie (Jet Engines, Their Development and Application), p. 5, Moskva, 1947; F e o d o s 'e v , V. I. and G. B. S i n y a r e v , Vvedenie v raketnuyu tekhniku (Introduction to Rocketry), p. 7. Moskva, 1960.

[7-18] A list of the works devoted to this question is given in the article of M a v r o d i n , V. V. O poyavlenii artillerii na Rusi (The Appearance of Artillery in Russia). — Vestnik Leningradskogo Universiteta, No. 3, pp. 66 — 75, 1946, and in the book, F e d o r o v , V. G. K voprosu o date poyavlenii artillerii na Rusi (On Dating the Appearance of Artillery in Russia), pp. 8 — 12. Moskva, 1949. Among more recent works the following articles should be mentioned: V i l i n b a k h o v , V. B. and A. N. K i r p i c h n i k o v , K voprosu o poyavlenii ognestrel'nogo oruzhiya na Rusi (On the Appearance of Firearms in Russia). — In: Sbornik issledovanii i materialov Artilleriiskogo istoricheskogo muzeya, No. 3, pp. 242 — 253, Leningrad, 1958; V i l i n b a k h o v , V. B. K istorii ognevogo oruzhiya v drevnei Rusi (On the Early History of Firearms In Russia). — In: Sovetskaya Arkheologiya, No. 1, pp. 284 — 288, 1960; K u z a k o v , V. K. K voprosu o poyavlenii ognestrel'nogo oruzhiya na Rusi (On the Appearance of Firearms in Russia). Lecture delivered at a session of the Department of the History of Mechanical Engineering, Institute of the History of Natural Science and Engineering, AN SSSR, in October 1962.

19 For a more detailed treatment of gunpowder production in Russia in the 15th and 16th centuries, see Luk'yanov, P.M. Istoriya khimicheskikh promyslov i khimicheskoi promyshlennosti Rossii do kontsa XIX veka (A History of Chemical Plants and of the Chemical Industry in Russia Down to the End of the Nineteenth Century), Vol. V. M., pp. 119—127, 1961.

20 Fronsperger, L. Kriegsbuch, Th. 1. Von Kayserlichen Kriegsrechten Malefitz und Schuldhändeln, Ordnung und Regiment. Frankfurt am Main, 1571; Schmidlapp, J. Künstliche und rechtschaffene Feuerwerk. Nürnberg, 1590.

21 A number of works on the history of Russian rocket artillery claim that military, if not flare rockets, were used in Russia as early as the 15th and 16th centuries. To substantiate their claims, the authors of these works cite the manuscript "A Manual of Matters Related to War, Guns, etc." (Ustav ratnykh, pushechnykh i drugikh del...), compiled by Onisim Mikhailov in 1607—1621 and printed at Sankt-Petersburg in 1777—1781. They regard its information on rockets as testimony to their use in the period preceding compilation of the manuscript, i.e., before the beginning of the 17th century. However, one must remember that Mikhailov's manuscript is not an original work, but, as the heading of the title page shows, a collection of 663 decrees or articles selected from foreign military books. It therefore cannot serve to confirm the use of rockets in Russia before the 17th century. Further information about Mikhailov's manuscript will be found in Rainov, T.I. Nauka v Rossii XI-XVIII vv. (Science in Russia from the 11th to the 18th Century). Moskva, 1940.

22 Bogdanov, A. Istoricheskoe, geograficheskoe i topograficheskoe opisanie Sankt-Peterburga ot nachala zavedeniya ego, s 1703 po 1751 god (A Historical, Geographical, and Topographical Description of Sankt-Petersburg from Its Founding in 1703 up to 1751), p. 510. Sankt-Peterburg, 1779.

23 A.M.L. Gollandets Klenk v Moskovii (The Dutchman Klenk in Muscovy). — In: Istoricheskii Vestnik, Vol. LVII, p. 770, 1894.

24 Historisch Verhael, of Beschriyving van de Voyagie, gedaen onder de Suite van den Heere Koenrad van Klenk, Extraordinaris Ambassaudeur van haer Hogmog de Heeren Staeten Genera, en sijn Hoogheyt den Heere Prince van Orange, aan sijne Majestyt van Moscovjen. Amsterdam, 1677. The book was translated into Russian at the end of the 19th century.

25 Quoted from the Russian translation. See: Posol'stvo Kunraada fan-Klenka k tsaryam Alekseyu Mikhailovichu i Fedoru Alekseevichu (The Embassy of Koenrad van Klenk to Tsars Aleksei Mikhailovich and Fedor Alekseevich), pp. 342—343. Sankt-Peterburg, 1900.

26 Tsytovich, P. Opyt ratsional'noi pirotekhniki (Experiment in Efficient Pyrotechnics), Part 2, p. 659. Sankt-Peterburg, 1894; Primenko, A.E. op. cit., p. 12; Sonkin, M.E. Iz istorii russkoi raketnoi artillerii XIX veka (A Contribution to the History of Russian Rocket Artillery in the 19th Century). — Informatsionnyi

Listok, No. 24, p. 2, 1949; Shesternikova, L. Daty istorii otechestvennoi aviatsii i vozdukhoplavaniya (Dates in the History of Russian Aviation and Aeronautics), p. 9, Moskva, 1953; Feodos'ev, V. I. and G. B. Sinyarev. Vvedenie v raketnuyu tekhniku (Introduction to Rocketry), p. 9. Moskva, 1960.

27 See Appendix 1, pp. 168—169.

28 State Historical Museum, Written Sources Division, store 440, file 378, sheet 1.

29 Tagebuch des Generals Patrick Gordon, Vol.II, p.297. St. Petersburg, 1851; Bogoslovskii, M. M. Petr I. Materialy dlya biografii (Peter I. Materials for a Biography), Vo. I, p. 99. Leningrad, 1940.

30 Tagebuch..., Vol. II, pp. 334, 366, 399.

31 Kniga Marsova ili voinskikh del (Book of Mars or of Military Matters). Sankt-Peterburg, 1713.

32 "Khudozhestva ognennyya i roznye voinskiya orudiya, ko vsyakim gorodovym pristupam i ko oborone prilichnyya, izdatelem Iosifom Boilotom Langrini izobretennyya" (The Arts of Pyrotechnic Weapons and Other Military Ordnance for All Policing Operations and for the Defense of Decency, Invented by the Publisher Joseph-Boilot Langrini). Manuscript Division of the Library of the AN SSSR in Leningrad. Peter I Gallery, No. 53.

33 Manuscript Division of the Library of the AN SSSR in Leningrad. Press-mark 17.15.2.

34 Ibid. Principal Collection. Press-mark 16.6.32.

35 Manuscript Division of the Library of the AN SSSR in Leningrad. Peter I Gallery, No. 38.

36 Böckler, G. A. Manuale Architeckturae Militaris oder Hand-büchlein über die Fortification and Festungsbaukunst. The first edition appeared in 1645—1647 in three parts. The fourth part, which contained information on rockets, was written in 1660 and probably published in the same year, but the Russian translation of this part was made and published only in 1672. The translation is kept in the Manuscript Division of the library of the AN SSSR in Leningrad, Peter I Gallery, No. 5.

37 Quoted from the Russian translation. See Böckler, G. A. Kratkaya arkhitektura voinskaya. Manuscript Division of the Library of the AN SSSR in Leningrad. Peter I Gallery, No. 5, sheets 189—189 obverse.

38 Artis Magnae Artilleriae, Pars Prima; Studio et Opera Casimiri Siemienowicz, Equitis Lithuani, olim Artilleriae Regni Poloniae Propraefecti. Amsterdam, 1650.

39 On this see the article of Subotowicz, M. Kazimierz Siemienowicz i ego wklad do nauki o rakietach (Casimir Siemienowicz and His Contribution to Rocketry).— Kwartalnik historii nauki i techniki, No. 3, pp. 491—492, 511. Warszawa, 1957.

[40] Noveishee osnovanie i praktika artillerii Ernesta Brauna, Kapitana artillerii vo Gdanske 1682 goda (Modern Theory and Practice of Artillery, by Ernest Braun, Captain of Artillery in Danzig, 1682). Moskva, 1709 (a second edition, identical to the first, was published in 1710).

[41] Uchenie i praktika artillerii ili vnyatnoe opisanie v nyneshnem vremeni upotreblyashchiesya artillerii, kupno so inymi novymi i vo praktike osnovannymi maniry, ko vyashchemu izucheniyu vse predlozhenno nadobneishikh chertezhei. *Izyasneno porutchikom Ioannom Zigmuntom* Bukhnerom (The Theory and Practice of Artillery, or A Clear Description of the Artillery Presently in Use, Together with Other New Forms, Established by Practical Use, with Most Useful Drawings for Fullest Study. Explained by Lieutenant Johann Siegmund Buchner). Moskva, 1711.

[42] Notes of Just Jull. — Russkii Arkhiv, No. 5, p. 36, 1892.

[43] AIM Archive, Arsenal Store, entry 9, file 112, sheet 3.

[44] Ibid., sheet 42.

[45] Ibid., sheet 148.

[46] Bogdanov, A. Istoricheskoe, geograficheskoe ..., p. 71.

[47] Danilov, M. Nachal'noe znanie teorii i praktiki v artillerii s priobshcheniem gidrostaticheskikh pravil (Rudiments of Artillery Theory and Practice with an Appendix on the Laws of Hydrostatics), pp. 72—74. Moskva, 1762; and, by the same author, Dovol'noe i yasnoe pokazanie, po kotoromu vsyakii sam soboi mozhet prigotovlyat' i delat' vsyakie feierverki i illyuminatsii (A Full and Clear Explanation of How to Make All Kinds of Fireworks and Artificial Illuminations). Moskva, 1779. The latter work was twice reprinted, in 1783 and 1822.

[48] Danilov. Dovol'noe i yasnoe pokazanie..., p. 8. Moskva, 1779.

[49] Vessel', E. Nachal'nye osnovaniya artilleriiskogo iskusstva (Fundamentals of the Art of Artillery), p. 294. Sankt-Peterburg, 1831.

[50] *Ibid., p. 203.*

[51] Lieutenant-Colonel F. S. Cheleev, Commanding Officer of the Sankt-Petersburg Artillery Laboratory, reported at the beginning of the 19th century that he knew over 100 formulas for compounding rocket mixture (Cheleev, F. Polnoe i podrobnoe nastavlenie o sostavlenii uveselitel'nykh ognei, feierverkami imenuemykh (Full and Detailed Instructions for Creating the Entertaining Illuminations Known as Fireworks), p. VIII. Sankt-Peterburg, 1824).

[52] A quite detailed, though insufficiently complete description of fireworks displays and illuminations held between 1675 and 1891 is given in Rovinskii, D. A. Opisanie feierverkov i illyuminatsii (Description of Fireworks and Illuminations). Sankt-Peterburg, 1903. (Rovinskii erroneously dates the fireworks display in Ustyuga to 1674 instead of 1675, however.) At present the most detailed information on Russian fireworks in the 18th and 19th centuries is to be found in Luk'yanov, P. M. op. cit., pp. 82—114.

53 Bogdanov, A. op. cit., p. 511; Rovinskii, op. cit., p. 206.

54 Zapiski Yusta Yulya, datskogo poslannika pri Petre Velikom (1709—1711) (Notebooks of Just Jull, Danish Ambassador to the Court of Peter the Great from 1709 to 1711), p.134. Moskva, 1899; Doneseniya chrezvychainogo angliiskogo poslannika pri russkom dvore Charl'za Vitvorta (Dispatches of Charles Whitworth, Extraordinary English Ambassador to the Russian Court). — In: Sbornik Imperatorskogo Russkogo Istoricheskogo Obshchestva, Vol. 50, p. 299. Sankt-Peterburg, 1886.

55 TsGADA, store 9, section I, file 55, sheets 13—14 (original pagination).

56 From the autobiography of Rasmus Erebo, in the book "Zapiski Yusta Yulya," p. 447.

57 Rovinskii, p. 303.

58 Ibid., pp. 286—293.

59 These notes have so far not been discovered. The information about the work of Korchmin and Skornyakov-Pisarev has been taken from Danilov, p. 3. See also Russkii biograficheskii slovar' (Russian Biographical Dictionary), Vol. 9, p. 295. Sankt-Peterburg, 1903.

60 For more detailed information about Lomonosov's work on pyrotechnics see the article of Pavlova, G. E. Proekty illyuminatsii Lomonosova (Illuminations of Lomonosov's Design). — In: Lomonosov, Sbornik statei i materialov, part IV, pp. 219—237. Moskva-Leningrad, 1960.

61 The list of those who participated in the preparation of fireworks has been compiled from examination of the above-mentioned books (Danilov, Rovinskii, Tsytovich, etc.). as well as from prints which often indicated the surnames of those who designed and executed the fireworks.

62 For more detailed information about Kulibin's work in this area, see the book "Manuscripts of I. P. Kulibin in the Archive of the AN SSSR" (Rukopisnye materialy I. P. Kulibina v Arkhive Akademii nauk SSSR), Papers of the Archive, No. 11, pp. 435—455. Moskva-Leningrad, 1953.

63 Cheleev, p. VII.

64 Ibid., p. IX. Cheleev's formula evidently corresponds to that of Russian military gunpowder.

65 Cheleev, p. X. Here, however, Cheleev was in error. As later experiments showed, increasing the volume of the ignition channel did not increase, but decreased the power of the propellant (see p. 68 below).

66 Ibid., p. 96.

67 Ibid., pp. 97—98.

Chapter II

THE EARLIEST MILITARY APPLICATION OF ROCKETS IN RUSSIA

Rockets were apparently first used as weapons nearly 1000 years ago in the countries of the east. A few cases of the military application of rockets were mentioned in the preceding chapter. They were very widely used in the 13th century, when they were employed as weapons by the Chinese, Arabs, Mongols, and other eastern peoples.

Gradually, however, as artillery improved, rockets began to lose their military value. By the 14th and 15th centuries rockets were being used far less frequently for military purposes, and by the 16th and 17th centuries had almost completely been abandoned in military actions.

The military application of rockets remained a dead letter until its revival at the end of the 18th and beginning of the 19th centuries. Although, as before, rockets were inferior to artillery in accuracy and range, their en masse application was quite effective.

The first to have experience of them were the English troops who clashed with Indian rockets at the end of the 18th century. After this, military rockets found application in England and elsewhere in Europe.

A great role in the development of rocket weapons during the first quarter of the 19th century was played by the English military engineer W. Congreve (1772—1826), after whom military rockets in all the countries of Europe were named for a long time afterwards.

At first Congreve's military rocket designs consisted of cylindrical casings of sheet iron, stuffed with rocket propellant. The forward part of the casing housed a core with an igniting compound. The rockets were stabilized by a lateral tail attached to the main body by a copper ring. Later (after 1813) Congreve modified his rocket design, replacing the cylindrical body by a conical one, and the lateral tail by a central one, attached to the base plate by a special bushing.[1]

In 1805—1807 English troops first used military rockets in the siege of Boulogne, and with particular success, in the siege of Copenhagen. Subsequently rockets were used as armament in Austria, Denmark, Prussia, France, and other European countries.

The question of using military rockets also arose in Russia, where a Military Study Committee had been considering it for a number of years. It was at first assumed that the successes of the English were due to the special qualities of the igniting mixture used in their rockets. In the first years, therefore, all effort was concentrated on determining the chemical composition of the igniting substance used in English military rockets. The Military Study Committee twice (in 1810 and 1813) performed chemical analyses of the igniting compound of the English rockets, but reached the

conclusion that "there is nothing special in the propellant and that these rockets do not possess any new means of ignition with special properties, but only an adaptation of the rocket's impulsive force for long-range application of a conventional ignition compound without having to employ heavy artillery for the purpose."[2]

The Military Study Committee then concentrated its attention on the development of rocket designs. In its report to Main Headquarters the Committee noted that it had "pursued research on the mechanical part in the conviction that the impulsive force of the rocket depends for the most part on the strict observance of perfect accuracy in the dimensions of casings and tails, in the proportionality of the ramrod and the exactness and finish of the instruments used in packing the rockets, in the correctness of mixing and the manufacture of the substances in the outlined ... proportion and most of all in their expert and accurate packing."[3]

After a number of unsuccessful experiments Kartmazov, a member of the Military Study Committee, succeeded, in 1814, in building incendiary and explosive rockets. During experiments held with his rockets in July 1814, the following results were obtained: high-flying large-caliber incendiary rockets (91.44 mm) attained a maximum range of 1260 sagenes (2690 m), while a small-caliber (50.8 mm) rebounding rockets with explosive reached 800 sagenes (1710 m).[4]

TABLE 2. Results of experiments with Kartmazov's rockets

High-flying incendiary rockets of 3.5" caliber			Rebounding incendiary rockets of 2.5" caliber		
No.	Angle of climb	Range in sagenes [yds given in brackets]	No.	Angle of climb	Range in sagenes [yds given in brackets]
1	35°	*	1	12°	650 [1517]
2	55	1395 [3255]	2	12	**
3	55	1368 [3192]	3	12	700 [1633]
4	52	1250 [2917]	4	12	650 [1517]
5	55	1320 [3080]			
6	50	1050 [2450]			

Rebounding rockets of 3.5" caliber			Rebounding rockets of 2.5" caliber with explosive		
No.	Angle of climb	Range in sagenes [yds given in brackets]	No.	Angle of climb	Range in sagenes [yds given in brackets]
1	15°	1050 [2450]	1	12°	***
2	15	1150 [2683]	2	12	550 [1283]
			3	0 (From platform)	480 [1120]
			4	0 (From platform)	480 [1120]

* Fell into marsh water and therefore not recovered.

** Fell into water and not recovered.

*** After striking the first reference wall broke its tail, after which it went off course and was not recovered.

These results testified to the good quality of Kartmazov's rockets, since the maximum range of Congreve's rockets did not exceed 3000 yards (2740 m). The testing of Kartmazov's rockets was later repeated, and in 1817 the Russian War Ministry decided to introduce military rockets into the army. Cheleev, the Commander of the Sankt-Peterburg Artillery Laboratory, was instructed to have several such rockets, intended for use in maneuvers, manufactured under Kartmazov's direction.[5] The results of the experiments carried out with Kartmazov's rockets in April 1817[6] are given in Table 2.

In these same years, independently of the Military Study Committee, one of the outstanding Russian scientists working on artillery, A. D. Zasyadko (1779—1837), was also working on the construction of military rockets. He began to experiment with various types of rockets in 1815, and rapidly attained success.

"Always regarding it as a duty entrusted to me and my special happiness to be as useful as possible to the service ...," Zasyadko wrote in 1817, "I sought to discover how rockets might be used for incendiary purposes, and although I never had any opportunity to see, much less to obtain information as to how the English manage so to use them in war, I nonetheless thought that what they claim as such an extraordinary and important discovery is nothing other than a properly adapted conventional rocket. My experiments have fully justified this opinion, showing that the rockets used in warfare are quite conventional."[7]

TABLE 3. Principal data on rockets designed by A. D. Zasyadko[8]

	4"	2.5"		2"	
Length of casing*	711.2	444.6	317.5	355.6	254.0
Thickness of casing walls	1.27	1.27	1.27	1.27	1.27
Thickness of base plate	2.54	2.54	2.54	2.54	2.54
Length of ignition channel	508	317.5	222.25	254.0	117.8
Diameter of exhaust orifice	38.1	25.4	25.4	22.86	22.86
Diameter of ignition channel	15.24	7.62	7.62	7.62	7.62
Thickness of a layer of wrapping paper	0.6	0.6	0.6	0.6	0.6
Length of cylinder at cap	233.68	—**	—	—	—
Length of external side of cone	254	—	—	—	—
Length of tail	5334.0	—	—	—	—
Maximum thickness of tail (at point of attachment)	50.8	31.75	31.75	25.4	25.4
Minimum thickness of tail (at free end)	38.1	25.4	25.4	25.4	25.4
Weight of tail in pounds	12—16.5	3—4.5	—	—	—

* Dimensions given in millimeters throughout.

** n.a.

By varying the thickness of the casing walls, the power of the propellant, and the dimensions of the ignition channel, Zasyadko attempted to obtain the optimum relationship between these three quantities, and he finally achieved positive results (Table 3). At the beginning of 1817 Zasyadko demonstrated the performance of his rockets in Petersburg,

and between July and December of the same year performed a great number of experiments with high-flying and rebounding rockets manufactured in a pyrotechnic laboratory built specially for the purpose in the town of Mogilev. Second Lieutenant V. Vnukov, K. Vaulin, Artillery NCO, and A. Vanchinov, a Bombadier, participated in the preparation and performance of Zasyadko's experiments.[9] The results obtained are shown in Table 4.[10]

TABLE 4. Results of experiments with Zasyadko's rockets

Angle of climb in degrees	Range in sagenes	[yds given in brackets]
4" incendiary rockets		
55	760—1250	[1773—2917]
50	725—1229	[1692—2968]
45	700—923	[1633—2154]
2.5" incendiary rockets		
35	600—750	[1400—1750]
30	400—645	[933—1505]
24—28	119—624	[278—1456]
18—22	117—275	[273—642]
12—15	72—219	[168—511]
10	93—207	[217—483]
4" rebounding rockets (inserted into wooden spheres)		
—	225—330*	[525—770]
2.5" rebounding rockets (inserted into wooden spheres)		
—	125—225*	[292—525]

* For the most part kept to correct direction.

The maximum range attained during these experiments was thus 2670 m. This time, however, accuracy, as well as range, was an objective, and from this point of view many of the rockets proved unsatisfactory, deviating considerably from the given direction. Zasyadko came to the conclusion that "... although a launching elevation of 55° gives the longest range, it produces greater deviations than at smaller elevations..."[11]

It is of some interest that although Kartmazov and Zasyadko worked independently of each other, their results were almost the same, their proposed rocket designs differing only in minor details. Even the dimensions of the fundamental components were almost identical (Table 5). This was probably to be explained by the fact that Kartmazov and Zasyadko both began with the assumption that "a military rocket is a conventional rocket," and in the course of their research relied upon the cumulative experience of Russian pyrotechnicians. As a result they used the traditional ratios of caliber and casing length (1 : 7), dimensions of the

ignition channel and rocket tail, and traditional values of a number of other structural features characteristic of pyrotechnic rockets.

TABLE 5. Comparative data on Russian military rockets at the beginning of the 19th century

	Kartmazov's rockets	Zasyadko's rockets
Diameter of casing	4"	4"
Length of casing	30"	28"
Thickness of casing walls	.06 — .07"	.042"
Thickness of base plate	.075"	.083"
Length of ignition channel	20.5"	20"

The military rockets proposed by Kartmazov and Zasyadko were subdivided into high-flying rockets, which had a high launching elevation (35 — 55°) and produced high angle fire, and rebounding rockets, which were launched almost horizontally, or at a low elevation (8 — 12°), and were used for target fire.

The rocket warhead consisted either of a cap with an incendiary mixture or of explosive, and the corresponding rockets were termed respectively incendiary and explosive (or often simply military).

The basic difference between the military rockets of the first quarter of the 19th century and firework rockets lay in the composition of the payload and in the material of which the casing was made. Furthermore, in firework rockets the rocket and pyrotechnic propellants were included in a single casing and from a manufacturing point of view constituted a whole, whereas in military rockets the casing and the warhead were quite distinct, being manufactured separately and joined only when the rocket was finally assembled.

Military rockets were manufactured by a process only slightly different from that used in the manufacture of firework rockets. A cylinder (the casing) equal in length to 7 — 7.5 times the rocket caliber was prepared from 1.3 — 2 mm sheet iron soldered with copper. Heavy paper was pasted over the interior of the casing to protect it from rust. A copper base plate with a hole in its center was soldered on to one end of the casing, and during the packing of the casing with propellant a ramrod was inserted through this hole to form the ignition channel (after packing this opening served as an exhaust orifice for the gases formed by combustion of the propellant).

The casing was then seated plumb on the ramrod and, after being fastened in an oaken mold, was packed with propellant, which was stuffed in installments following a definite sequence, the size of the installments, and the number and force of the blows, being strictly regulated in accord with the caliber of the rocket. Approximately 70 % of the length of the casing was occupied by the ignition channel, and between 14% and 21 %, by a layer of blind propellant. The remainder was packed with silt, in the middle of which a small hole was made to allow the passage of fire from the propellant to the incendiary substance.

After this, depending on the function of the rocket, either a separately built head (cap) with incendiary compound, or an explosive was attached to the casing (Figures 8 and 9).

The cap was 5 rocket calibers in length and consisted of two approximately equal parts, one cylindrical and the other conical. The internal diameter of the cylindrical part was made equal to the external diameter of the casing. To ensure a more durable union of cap and casing, longitudinal slots were made in the cylindrical part of the cap, and after it had been tightly fitted over the casing, glass yarn was wound around over their entire length.

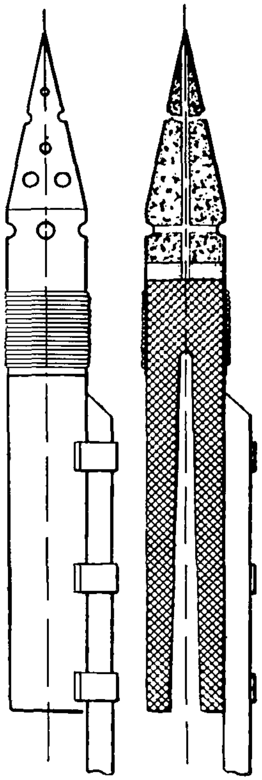


FIGURE 8. High-flying incendiary rocket designed by Zasyadko.

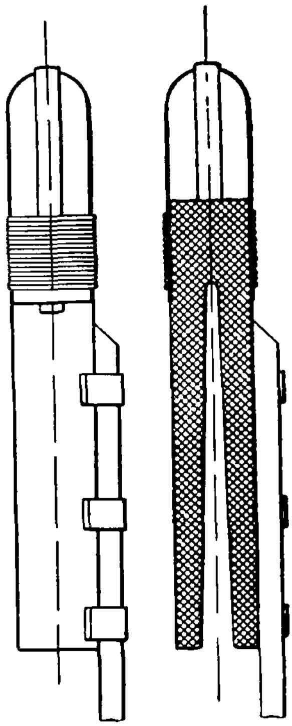


FIGURE 9. Rebounding rocket with explosive, designed by Zasyadko.

The explosive, which also was situated at the forward end of the rocket, was attached in a somewhat different fashion. Over it were placed crosswise two bands of sheet iron, 15" long and half an inch wide, which were then attached to the rocket like the cap. This method of coupling cap and explosive was simple and for the time, quite secure.

Despite the success of the experiments of Kartmazov and Zasyadko in 1817, the problem of mass production of military rockets in Russia did not find a practical solution for a long time. Experiments continued as before for almost 10 years, and Zasyadko was urged to repeat his tests in 1821.[12]

In 1823 Massingbird-Turner, a British subject, was attracted to the manufacture of military rockets in Russia. Under his direction 2", 3", and 4" rockets for experimental purposes were built at the Okhtensk Gunpowder Works.

The major difference between the rockets manufactured by Massingbird-Turner and those designed by Kartmazov and Zasyadko was in the use of a central, rather than a lateral tail. The report of the "Committee for Testing of the Congreve Rockets Prepared by the Englishman Turner" remarked that his "rocket tails had iron screws at one end, by which they were screwed to the iron base plate of the rocket with 5 holes and a thread in the center."[13]

In June 1824 Turner's rockets were tested on the Volkova field, with the following results:

"1) Three 2" rockets (according to our caliber, 1 1/2-pounders) with grenades of almost one-pound caliber were launched one after another from a portable stand through a brass tube 5 feet long, at an elevation of 25 degrees, and at a distance of 400 sagenes [933 yards] from the rampart. They followed quite a straight course and fell about 80 sagenes [187 yards] behind the rampart.

"2) Fourteen rockets of the same caliber, also launched separately at an elevation of 22.5 degrees, rebounded 120 sagenes [280 yards] in front of the rampart. Most of them flew over it, others dropped into the water before it, and three landed on the rampart itself. One took to the left and another continued on course, after breaking its tail.

"3) To show the extraordinary flight of this caliber, one rocket launched at an elevation of 45° covered a distance of 764 sagenes [1783 yards].

"4) Two volleys of four rockets were produced by a special stand modeled on those used by the English for this purpose. The advantage of tails in the center, or attached to the rocket axis, as well as the convenience of this type of launching (assuming improvement of the firing mechanism) are evident. They were launched at 20° and made three rebounds, after which the shells burst, flying as far as the rampart.

"5) A 3"-rocket (in terms of our calibers, almost an 8 1/4-pounder) with a 4 1/2-lb shell or a body carrying 8 lb of incendiaries, achieved a range of 900 sagenes [2100 yards], but is capable of even more...

"6) A rocket of this type, with body packed with incendiaries, was attached to a wooden pole in order to show how fast the incendiary burns after the rocket has been completely consumed. The incendiary burned for eight minutes.

"7) The body of a 4" rocket with incendiary (a 13-pounder) was burned in the same way in order to show how much fire it can eject. It burned for 11 minutes, emitting through holes in all directions an extremely fierce flame nearly a foot in length, as well as sparks. After it had burned for eight minutes, the iron around the holes through which the flames were forced out began to melt."[14]

These experiments gave the Ministry of War a basis for reconsidering the adoption of military rockets as a form of armament. In August 1824 the chief of the general staff I. I. Dibich proposed the use of military rockets in military actions to A. P. Ermolov, Commander of the Caucasus Detachment.[15]

Ermolov supported this idea and expressed himself as definitely in favor of using military rockets in the Caucasus with the comment that "they can be of great help to us in the mountains, but even more against enemies whose

cavalry greatly outnumbers ours."[16] Subsequently he twice requested the general staff to speed up the delivery of rockets to the Caucasus, but the War Ministry did not possess a sufficient number of military rockets. Furthermore, some of the army staff commanders still doubted the performance of rockets and felt that until repeated experiments had been performed the question of the troops' using rocket armaments could not even be raised. Repeated experiments were made only a year later, in August 1825. This time the rockets were launched from iron tubes, and from a stand which had eight longitudinal chutes for the simultaneous launching of eight rockets. The experiments gave the following results:[17]

Caliber of rockets	2"	2.5"	3.25"
Range in sagenes [yds given in brackets]	45 — 385	170 — 800	250 — 1000
	[105 — 898]	[397 — 1867]	[583 — 2333]

Of the 76 rockets launched, 14 kept right on course, and the others showed deviations of from 2 to 50 sagenes [5 to 117 yards]; a single rocket had a deviation of 77 sagenes [180 yards].

The reaction to these experiments was extremely contradictory. The committee specially created to examine the quality of the rockets manufactured under Turner's direction reached the conclusion that the rockets tested did not justify the hopes placed in them.

"In considering the results of these experiments," ran the report made to the Master of the Ordnance in September 1825, "the Committee found that the range of these rockets is inadequate and not constant for the same launching elevation, that their momentum is not great enough, so that, as far as is known from descriptions, they fail to achieve the effects ascribed to Congreve rockets. For these reasons only a few small-caliber rockets, launched en masse along the ground, without a stand, can be useful against cavalry, or can break its ranks by frightening the horses. Elsewhere, they can be of use for the defense of fortifications. The incendiary used to stuff the warheads of the large-caliber rockets, however, was found satisfactory."[18]

The Master of the Ordnance, however, did not agree with this opinion, and found the results of the experiments entirely satisfactory, noting that "these projectiles can inflict considerable harm at quite a great distance, their use is entirely safe and can therefore be of great value, especially in mountainous regions and against uneducated troops."[19]

On the basis of this opinion, and taking into account Ermolov's repeated requests for the shipment of military rockets to the Caucasus, the Artillery Department recognized the necessity of getting rocket production going in Russia and urged the creation of a special "rocket establishment" for this purpose.

A practical solution of the problem of mass producing rockets in Russia dates from the second half of the 1820's. In March 1826 it was decided to create a permanent rocket establishment in Sankt-Petersburg.[20] Its initial location was in the Okhtensk Gunpowder Works. Lieutenant-General Kozen was named Manager of the Petersburg Rocket Institute, and Massingbird-Turner, Director.[21] In the same year, 1826, one of the three companies of the 3rd Field Artillery Brigade was detached for "training in the preparation and operation of rockets," and in 1827 its name was changed to the Permanent Rocket Company.[22] One of Zasyadko's closest assistants, Captain Vnukov, headed this company.

The first order received by the Petersburg Rocket Institute was the manufacture of 3000 rockets for the Caucasus Detachment. The first installment of 1000 rockets ready for use (200 12-pounders with balls, 100 12-pounders with incendiaries, 200 12-pounders with explosives, 200 6-pounders with balls, and 300 6-pounders with explosives), and 1770 empty casings (422 12-pounders and 1348 6-pounders) to be filled locally, was sent off to Tiflis in February 1827.[23]

In June of the same year the rockets delivered from Petersburg were tested in Tiflis under the direction of the military governor Sipyagin. The results were completely unsatisfactory (most of the rockets burst before launching), which in the opinion of those conducting the experiments showed that the rockets could not be transported great distances.

The experimental rockets manufactured locally gave considerably better results. In August 1827 military rockets were twice used against enemy troops, and both times with success: in the battle of Ushagan and against cavalry near Alagöz. Furthermore, three rockets were successfully launched against the Ardebil Fortress.[24] These are apparently the first instances of the use of military rockets against an enemy by Russian troops.

On the basis of the results of tests, as well as of the first experience in the use of rockets during military actions, General Paskevich, who succeeded Ermolov in the command of the Caucasus Corps, arrived at the following conclusion, which he presented in his dispatch to Main Headquarters in April 1828:

"1. The rockets sent from Sankt-Petersburg were ruined, while those assembled here were quite good; however, very calm weather is prerequisite to their use, otherwise the wind always changes their direction.

"2. It is highly inconvenient to transport them, since this results in damage to the rockets."[25]

Table 6 gives an idea of what sort of rockets and in what numbers issued from the Petersburg Rocket Institute in the years 1828—1829, and testifies to the large scale on which the work was done. Actually, however, only final assembly and stuffing of the rockets was done in the Rocket Institute itself, manufacture of the individual parts being taken care of in various plants. For example, the rocket casings were supplied by the Armaments Workshop of the Sankt-Petersburg Arsenal,[26] the base plates, caps, and explosives, by the Aleksandrov plant,[27] and the gunpowder pulp came from the Okhtensk Gunpowder Works.

During the Russo-Turkish war of 1828—1829 military rockets were comparatively widely used by the Russian troops, e. g., in 1828 near Shumla and in the siege of Varna, and in 1829, at the siege of Silistria.

The opinions of scientific historians as to the influence of this first Russian experience in the mass use of rockets in military actions are completely contradictory. This is to be explained by the two different impressions made by military rockets on different military circles.

On the one hand it must be admitted that this first experience was not particularly successful. The rockets manufactured in the Petersburg Rocket Institute did not justify the hopes reposed in them: they were of extremely poor quality, marked by inaccuracy and unreliability in use, and often inflicted damage upon the troops using them. This made a negative impression on a considerable part of the army command and led to the denial of any serious attention to rocket armament for almost two decades.

TABLE 6. Production of military rockets in Russia, 1828—1829

Caliber of rockets		According to the data for 12 January 1828*			According to the data for 1 February 1829**					According to the data for 21 August 1829†		
		Production intended	Launched in experiments and reviews	Balance	Production intended	Manufactured	Number used: In reviews and experiments	Number used: Against the enemy	Remaining from the first two details	New production intended	Manufactured	Still to be manufactured
36-pounders	military . . .	—	—	—	350	242	33	71	239	200	45	155
	incendiary . . .	—	—	—	1850	1396	36	180	941	1300	75	1225
20-pounders	military . . .	—	—	—	1900	1239	184	273	749	—	—	—
	incendiary . . .	1000	109	891	600	459	39	114	187	1000	84	916
12-pounders	military . . .	—	—	—	1919	1871	203	289	684	500	—	500
	incendiary . . .	1000	155	845	600	592	33	86	9	1000	394	606
6-pounders	military . . .	1000	268	732	2768	2591	420	178	936	2000	1277	723
Total		3000	532	2468	9987	8390	948	1191	3745	6000	1875	4125

* AIM Archive, GAU store, entry 3/2, file 157, sheet 201.

** TsGVIA, VUA store, entry 1, file 4790, sheets 33 obverse—34.

† Ibid., sheet 74.

On the other hand, the experience of military actions showed the potential of military rockets and increased the interest of military engineering circles in this new form of weapon and in broadening its military application.

In other words, military experience showed that rockets could become weapons in war, though they had not yet achieved this status in the period under consideration. It was clear that without substantial improvement of rocket armament there could be no question of its further use in the army, and a number of steps were therefore taken to improve and reorganize rocket production in Russia.

In 1832 all of the existing Russian rocket institutes were combined into one. The refounded Petersburg Rocket Institute, whose assignment was to "improve the performance of Congreve rockets and the means for their production," thus consisted of:

"a) a rocket laboratory for the preparation of military and incendiary rockets and

"b) a rocket battery to be used in laying siege to and defending fortresses, etc."[28]

All work on the production of military rockets in Russia was concentrated in this institute, but until the middle of the 1840's it hardly fulfilled its goals and contributed little to the development of rocketry in Russia. As K. I. Konstantinov, one of the greatest rocketry experts of later years, pointed out, "It existed only as a supplement to our technical institutes."[29]

In the 1830's a number of suggestions were made of various possibilities for the military application of rockets. In 1834 the Russian military engineer K. A. Shil'der (1785—1853), while continuing to improve his countermine system, suggested using rockets as a means of destroying siege engines in the defense of fortresses. For this purpose he recommended demolition rockets of special design, with a large quantity of powder, which would treble the range of their effectiveness against siege engines.

In 1834—1835, in Petersburg (on the Semenovskii parade-ground), in Krasnoe Selo and in the Novogeorgievskii Fortress Shil'der performed a number of experiments which confirmed the correctness of his calculations and demonstrated that rockets can successfully be used both in the siege and defense of fortresses. Subsequently he returned several times to this idea, renewing and broadening his program of experiments.

The success of Shil'der's scheme for the defense of fortresses depended to a great degree on the quality of the rockets, their accuracy, and the power of the charge. His first experiments, which demonstrated the destructive power of demolition rockets, also showed that it was desirable to improve their accuracy. Of the 128 rockets launched during the experiments of 19 July 1835, for example, only 57 hit the target, 67 overshot the mark and flew through the trenches, and four burst shortly after launching.[30]

For several years, therefore, the Petersburg Rocket Institute worked systematically to improve the rockets intended for Shil'der's experiments. Shil'der himself observed that after the experiments of 1835 the Rocket Institute "devoted all of its attention to the improvement of rocket flight," and added that the next experiments "would show, I am convinced, that rockets can hit their target with the same accuracy as ordnance."[31]

Together with improvement of the quality of military rockets, the Petersburg Rocket Institute also worked on means of substantially increasing the weight of the charge. One of the means of doing this and simultaneously increasing the accuracy of the shot still drew on the experience of pyrotechnics and consisted of the use of rocket clusters. The artisans of the Petersburg Rocket Institute successfully resolved this problem. "After the experiments made last year at Krasnoe Selo and the Novogeorgievskii Fortress," wrote Shil'der in 1836, "demolition rockets have been improved to the point where they perform as accurately in aerial flight as along the surface of the earth. The major result of this improvement is that several rockets of unit caliber have been combined into a cluster which moves considerable weights with high accuracy and speed. It will thus be possible to give the attack new means for the elimination of fortifications, for the added reason that, as experiments have shown, these rockets can be used to throw 2-, 3-, and 5-pud (i. e., 72-, 108-, and 180-lb) bombs with high accuracy."[32]

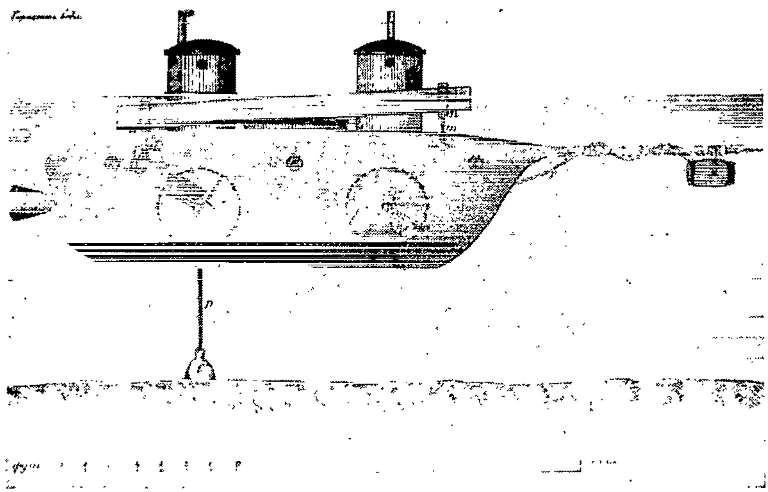


FIGURE 10. Submarine designed by K. A. Shil'der.

In these same years (1834—1838) Shil'der studied the possibilities of using military rockets in the navy. He proposed to launch rockets from a sort of submarine (Figure 10) as well as from a raft floating on the water or a rocket steamship specially intended for this purpose.[33]

In 1834 he designed and built a submarine carrying rocket launching equipment. The rocket stands consisted of vertical props with horizontal cruciform slats to which the iron tubes in which the rockets were placed were attached. Each of these stands could be used for the simultaneous launching of three rockets. The launching elevation of the stand could be varied by moving the forward prop. To protect the rockets from the water, the forward ends of the tubes were stoppered with plugs over which rubber caps were fitted. When the rockets were ignited by galvanic conductors, they forced out the plugs and continued on course.[34]

The following program of experiments was envisaged.

"1) Alongside the submarine," Shil'der wrote, "rockets of very big caliber will be launched along the surface of the water. They should have a range of 700 sagenes [1633 yards] or more along the directrix.

"2) Such actions from the submarine will be repeated against distant objects.

"3) Fougasses ignited between vessels 70 sagenes [163 yards] apart, such as ships, will probably burn their rigging by ejecting incendiary substances and

"4) The explosion of underwater mines will probably completely destroy these vessels.

"All these destructive projectiles are fired from the submarine by galvanism. At the end of these experiments the submarine surfaces and the crew come out on deck."[35]

The first submarine experiments were performed in August 1834.[36]

Subsequently Shil'der designed a second, barrel-shaped submarine distinguished from the first by a number of technical improvements. Experimental launching of rockets from submarines continued until the beginning of the 1840's, but failed to give positive results.

Independently of Shil'der's experiments the Petersburg Rocket Institute was working on the improvement of military rockets. In 1837 Lieutenant-General Kozen, manager of the Institute, proposed to parallel Shil'der's experiments with the testing of "complex rockets," or rocket clusters, manufactured by it. The clusters varied from 5 to 6 small-caliber rockets to 12 large-caliber rockets. Large-caliber rocket clusters contained as much as 1.5 pud [54 lb] of powder and were designed to throw 13- and 18-pud [468- and 648-lb] bombs.[37]

The Petersburg Rocket Institute also continued work on the improvement of conventional military rockets (2", 2.5", and 3.5"), but no notable successes were attained.

Examination of the state of rocket armament in Russia during the first half of the 19th century shows that Shil'der's evaluation of the PRZ rockets was greatly exaggerated. The military rockets of the 1830's and 1840's had a number of serious deficiencies, including comparatively short range, inaccuracy, and most important, unreliability.

Experiments on the intensification of fortress defense, carried out in 1839 in Novogeorgievsk, showed that high-angle firing of rockets gave satisfactory results only when the target was about 100 m distant. In other cases the rockets were widely dispersed. According to the report of the results, "the flight of rockets fired at a high angle over a longer range of from 50 to 450 sagenes [117 to 1050 yards] was completely untrue, with the result that of rockets with the same direction and launching elevation, some did not reach the target, others overshot it, and still others landed as far as 100 sagenes [233 yards] to left or right of it."[38]

The low quality of the rockets was to be explained to a large extent by imperfect manufacturing techniques. This was very well understood by those concerned with the production of military rockets in Russia. In November 1839 Lieutenant-General Kozen of PRZ noted that "most of the work is done by hand and is therefore to a great extent inaccurate. As a result, flight of the assembled rockets cannot be even approximately true."[39] He pointed out that in order to ascertain the capabilities of

rockets more attention to the improvement of manufacturing techniques would be required, but added that "because of the shortcomings of its machinery PRZ has no means for doing this."[40]

Before the mid 1840's Russian rocketry developed extremely slowly. The low quality of the rockets prohibited their widespread use. Another negative factor was the fact that military rockets received virtually no practical use throughout the 1830's and early 1840's. Furthermore, much of the army command, having the impression that rockets had not achieved any particular success in the Russo-Turkish war of 1828—1829, were skeptical about their adoption as a new form of armament and obstructed their introduction to military units. All of this brought about a considerable reduction in the production of military rockets for the army.

In the middle 1840's, however, the situation changed fundamentally, and the demand for military rockets rose sharply. This was explained by the wide use of rockets at that time in military operations in the Caucasus.

As early as October 1842, 500 1.5" incendiary rockets were ordered by the Caucasus Corps, and they were delivered to Georgievsk in March 1843.[41]

In this mountainous region difficult of access the superiorities of rockets over artillery, such as their lightness and availability for massed fire and for firing without heavy ordnance, were clearly evident.

At the beginning of 1845 M. S. Vorontsov, the Chief in Command of the Caucasus Corps, therefore requested the War Ministry to send a large shipment of military rockets to the Caucasus so that they could be used for "full battery action against the enemy."

Vorontsov first became acquainted with rockets as early as 1813, at the Battle of Leipzig, where for some time he served in place of the dead Commander of the English Battery. Subsequently he had several opportunities to observe rockets in action, both in war and in peacetime, at reviews and exercises.

In 1846 Vorontsov wrote to the Minister of War A. I. Chernyshev, urging the advisability of using rockets in the Caucasus, as follows: "... when I saw 3- and 4-pound rockets used in reviews and exercises at Woolwich itself, I immediately got the impression that they could be one of the most useful forms of ordnance, especially in mountainous terrain. Of course small guns are truer and can shoot canister-shot for defense, even if only over small distances, but all guns involve gun-carriages and caissons, in a word, trains. Even our mountain ordnance involves limbers, wheels, and pack horses. Rockets have none of this paraphernalia; wherever the cavalry go, they can carry as many small rockets as desired with them. Every horseman can carry a small rocket instead of a lance; the smallest stands are required, and if necessary may be altogether dispensed with. In a word, small rockets constitute a form of artillery which, while obviously not the best, can always be made available, in whatever quantity desired, in places where it is difficult, dangerous, or downright impossible to provide other forms of artillery, and whose quantity in some measure compensates for its qualitative deficiencies."[42]

In 1845 1000 six-pound (2") military rockets were delivered to the Caucasus.[43] This shipment was evidently successfully used in action, because in December of the same year Vorontsov requested another shipment, this time of 6000 rockets.[44]

The Petersburg Rocket Institute, however, was not ready to supply rockets in such quantity, since it was poorly equipped for quality mass production. As before, most of the work was done by hand and the working conditions were very difficult and hazardous.

The work was also greatly complicated by the fact that before 1846 PRZ had no established technique for the manufacture of military rockets. The resulting rockets therefore differed greatly both in quality and size. Only in 1847 did Colonel Kostyrko, manager of the Institute, prepare a special manual containing precise designations of rocket calibers, a description of rocket designs, and the ratios of fundamental components of the rocket mixture, as well as an explanation of the sequence of technological operations.

In these same years an effort was made to use rockets for the defense of coastal fortifications. Lieutenant-General Maslov, the builder of Risbank Fort in Kronshtadt considered the installation of special rocket loop-holes in the casemates planned for the fort.

Since the idea of arming marine fortifications with rockets was new it was decided to perform some preliminary experiments in a fort which had already been built in order to determine the potentialities of rocket fire from casemates and clear up a number of technical questions. Tests were accordingly made in August 1848 in the "Emperor Peter I" fort (Table 7).

TABLE 7. *Results of experiments on the firing of rockets from the casemates of the "Emperor Peter I" fort*

Launching elevation in degrees	Range in sagenes [yds given in brackets]	
2.5"		
0	Up to 75	[125]
2	125 — 150	[292 — 350]
3	150 — 175	[350 — 408]
4	175 — 200	[408 — 467]
5	225 — 250	[525 — 583]
6	Over 250	[583]
3.5"		
9	Up to 300	[700]
10	450 — 600	[1050 — 1400]
11	600 — 700	[1400 — 1633]

Note: *Altogether 40 rockets were launched (20 12-pounders and 20 36-pounders). After its first landing (range indicated in the table) each rocket rebounded once or more, covering an additional 50 to 100 sagenes [117 to 233 yards] on each rebound.*

In the report on these tests it was stated that "the flight of the rockets was flat and fully satisfactory, and their deviations from the direction of firing, indicated by rods set up for this very purpose, were quite insignificant." [45]

The tests demonstrated the advisability of arming shore fortifications with rockets and provided the experimental data required on the design of casemates and the size of the embrasures.

At the end of the 1840's the military rockets leaving the Petersburg Rocket Institute were to be numbered in the thousands. Rockets had become firmly established among the actual forms of armament of the Russian army.

NOTES

1 The information on Congreve's rockets is taken from W. Ley. Rockets Missiles and Space Travel, pp. 68—71. New York, 1958.

2 From the Report of the Military Study Committee, 14 June, 1818. TsGVIA, store 35, entry 4/245, code 188, sheets 74—74 obverse.

3 Ibid., sheet 74 obverse.

4 TsGVIA, store 35, entry 4/245, code 188, file 65, sheet 92 obverse.

5 TsGVIA, store 35, entry 4/245, code 188, file 65, sheets 5—7; see also AIM Archive, GAU store, entry 3/2, file 35, sheet 1.

6 TsGVIA, store 35, entry 4/245, code 188, file 65, sheet 12.

7 Zasyadko, A. D. O zazhigatel'nykh raketakh (Incendiary Rockets). Manuscript. — TsGVIA, store 35, entry 4/245, code 188, file 65, sheets 48 obverse —49.

8 The table was compiled from Zasyadko's autographical notes — TsGVIA, store 35, entry 4/245, code 188, sheet 65, sheets 24, 42, 43, 46 obverse.

9 Zasyadko, op. cit., sheets 33—40; see also store 35, entry 4/245, code 195, file 309, sheets 2—3.

10 The data are taken from notes compiled by Zasyadko in the form of a diary, where they were entered in chronological order. In the table they have been systematized and rearranged according to range and launching elevation. TsGVIA, store 35, entry 4/245, code 188, file 65, sheets 53—70.

11 Zasyadko, op. cit., sheet 64.

12 TsGVIA, store 35, entry 4/245, code 188, file 65, sheet 90; also ibid., code 194, file 241.

13 TsGVIA, store 35, entry 4/245, code 196, file 334, sheet 27 obverse.

14 Excerpt from the diary of the experiments. TsGVIA, store 35, entry 4/245, code 196, file 334, sheets 6—7.

15 TsGVIA, store 35, entry 4/245, code 196, file 334, sheet 3.

16 Ibid., sheet 9.

17 Ibid., sheets 27—29;

18 Ibid., sheets 24 obverse—25.

19 Ibid., sheet 34 obverse.

20 Resolution of 30 March 1826. TsGVIA, store 35, entry 4/245, code 196, file 334, sheet 34.

21 AIM Archive, GAU store, entry 3/2, file 157, sheet 114; see also Gunpowder Warehouse store, entry 24/3, file 31, sheets 11 obverse—14.

22 From the Minister of War's letter to the Artillery Department. AIM Archive, GAU store, entry 3/2, file 149, sheet 8.

23 TsGVIA, store 35, entry 4/245, code 196, file 334, sheet 49.

24 The information on the military use of rockets is drawn from the notes sent by Paskevich to Main Headquarters.— TsGVIA, store 35, entry 4/245, code 196, file 334, sheets 53—57.

25 Note on Congreve Rockets.— TsGVIA, store 35, entry 4/245, code 196, file 334, sheet 57.

26 AIM Archive, GAU store, entry 3/2, file 157, sheet 69.

27 TsGVIA, store 503, entry 4, file 784, sheet 34.

28 AIM Archive, Gunpowder Warehouse store, entry 24/2, file 300, sheets 75 obverse—76.

29 Konstantinov. O boevykh raketakh (Military Rockets), p. 64. Sankt-Peterburg, 1864.

30 A detailed description of the performance of demolition rockets and other missiles during the experiments of 19 July 1835 is given in TsGVIA, store 1(1), entry 1, file 9967, sheet 11 obverse.

31 TsGVIA, store 1 (1), entry file 9271, sheets 110 obverse—111.

32 Ibid., sheets 114 obverse—115.

33 Ibid., sheets 95—96, 111 obverse—112.

34 Mazyukevich, M. Zhizn' i sluzhba general-ad"yutanta Karla Andreevicha Shil'dera (The Life and Service of Adjutant General Karl Andreevich Shil'der), p. 193. Sankt-Peterburg, 1876.

35 TsGVIA, store 1 (1), entry 1, file 9271, sheets 30 obverse—31.

36 Ibid., sheet 25.

37 Ibid., sheet 130.

38 Zapiska o proizvedennykh v istekshem lete opytakh usileniya oborony krepostei po sposobu general-ad'yutanta Shil'dera (Report on the Experiments Performed During the Past Summer on the Intensification of Fortress Defense by the Method of Adjutant Genral Shil'der).— TsGVIA, store 1 (1), entry 1, file 11103, sheets 111 obverse—112.

39 Report of 1 November 1839.— AIM Archive, Gunpowder Warehouse store, entry 24/3, file 143, sheet 3 obverse.

40 Ibid., sheet 39 obverse.

[41] TsGVIA, store 503, entry 4, file 978, sheet 46.

[42] Quoted from the text in "Morskoi sbornik," No. 10, first section, subsection IV, p. 272, 1855.

[43] TsGVIA, store 503, entry 4, file 978, sheet 130.

[44] On this see AIM Archive, Gunpowder Warehouse store, entry 24/2, file 300, sheet 21.

[45] AIM Archive, ShGF store, entry 12, file 30, sheet 45.

Chapter III

ROCKET ARMAMENT OF THE RUSSIAN ARMY

RUSSIAN MILITARY ROCKETS OF THE 1850's AND 1860's

In Russia, as in most other European countries, the middle of the 19th century was the period when rocket weapons attained their greatest popularity. Although military rockets could not compete with artillery in accuracy and range, they were highly successful as a form of supplementary armament.

In this period military rockets were most widely employed in the Caucasus, where Russian troops continually saw action, and PRZ also equipped the troops in the Crimea, Central Asia, the Baltic region, Finland, and the Urals with rockets. Altogether about 33,000 military rockets were manufactured in Russia during the period 1846—1854.[1] An idea of the production and destination of the rockets in individual years[2] can be obtained from the "Note on the State of Our Rocket Unit" (Zapiska o sostoyanii u nas raketnoi chasti), submitted to the Inspector of Gunpowder Plants in August 1854.

1.	2" rockets	
	1846 shipped to Caucasus	3500
	1847 " " "	2000
	1848 " " "	3920
	1849 " " "	4000
	1849 " " Orenburg	400
	1850 " " Caucasus	4000
	1851 " " "	3700
	1852 " " "	1700
	1853 " " "	2000
	1853 " " Kerch	600
	1853 " " Orenburg	350
	1854 " " Caucasus	2000
	1854 " " Bucarest	2000
	1854 " " Revel	200
Ready for shipment:		
	to Sevastopol	600
	" Helsingfors	480
2.	3.5" demolition rockets	
	shipped to Caucasus after 1846	60
	In 1854 near Silistria	100
	Prepared without projectiles for the merchant Nobel	100

With the sharp increase in the number of military rockets produced by PRZ and used in the Russian army, the question of their quality, which formerly had left much to be desired, acquired new significance. Among the fundamental deficiencies of the Russian military rockets of the 1840's must be included their comparatively short range, considerable deviations from the target, and most importantly, unreliable functioning. Rockets often burst on the launchers, injuring the troops using them; furthermore, they did not sustain extended storage and transportation, which resulted in a distinct impairment of their quality and a sharp increase in the percentage of malfunctioning rockets. [3]

These defects were quite serious, and the extent to which rocket armament would be adopted by the army largely depended on whether they could be overcome. PRZ therefore could not avoid facing the problem of increasing the accuracy and reliability of its rockets.

After the middle of 1840's K. I. Konstantinov (1818—1871), who did a great deal for the development of Russian rocketry and was one of the greatest exponents of the Russian artillery school of the middle 19th century, began to work on the improvement of military rockets. In March 1850 he was appointed to the management of the Petersburg Rocket Institute, which was almost completely re-equipped in the course of several years under his direction (for more details see below).

At the end of the 1840's and the beginning of the 1850's Konstantinov performed a great many experiments, in which he and his colleagues attentively studied foreign experience in rocketry, considering the advantages and deficiencies of the rockets manufactured in various countries, in an effort to make use of every positive feature which found employment in foreign armies.

At this time the greatest popularity was achieved by two rocket schemes which differed both in design and in the action of the propulsive force: rockets with lateral and with central tails. The former were most widely used in Austria and as a result were often termed Austrian rockets, while the latter were introduced by Congreve during the first quarter of the 19th century and were called English rockets. This was the type adopted in Russia by the Petersburg Rocket Institute.

Both types had their advantages and drawbacks. The main difference between the two was that in rockets with a lateral tail the propulsive force was developed at the very beginning of flight and acted only for a short time. This was explained by the fact that rockets with a lateral tail did not generally have a base plate, so that the gases formed by combustion of the propellant, with nothing to obstruct them, could flow out freely. As a result it was possible substantially to increase the speed of combustion of the propellant, and consequently, to increase the initial velocity of the rocket. After burnout the rocket flew like a conventional projectile, following the laws of ballistics, propelled by its accumulated kinetic energy. The position of its center of gravity underwent no further change.

Both the increase in initial velocity and the constant position of the center of gravity over a considerable part of the trajectory made possible increase in accuracy, which was an important factor in the selection of designs for military rockets.

Konstantinov undertook an attempt to introduce rockets with lateral tails into Russia, but the comparative tests he made in 1848 showed that

despite the clear superiority of these rockets in aimed fire at short distances, which resulted from their uniformity and accuracy, it became less marked with increase in range. Furthermore, the rockets with lateral tails had generally shorter range than those of PRZ. Rockets with lateral tails were therefore finally rejected in favor of those with central tails.

Later Konstantinov began to work on adaptation of the positive features of both types, taking as his model the 2" military rockets (Figure 11) with central tail attached to a base plate with five exhaust orifices, produced by PRZ.

In Konstantinov's opinion the number of exhaust orifices was a matter of some importance. During the first half of the 1850's, therefore, PRZ conducted tests for the comparison of rockets with base plates differing in the number of their exhaust orifices and in their diameter (Table 8).[4]

TABLE 8. Some data on the rockets tested at the Petersburg Rocket Institute

Caliber	Number of exhaust orifices	Diameter of exhaust orifices, in	Ratio of total area of exhaust orifices to internal cross sectional area of rocket
2"	5	0.376	0.18
	5	0.45	0.26
	6	0.45	0.33
2.5"	5	0.55	0.25
	6	0.55	0.30
3.5"	5	0.8	0.22
	6	0.8	0.27

Experiments showed that the total area of the gas exhaust orifices had a decided influence on the magnitude of the reactive force. Decrease in the total area of the orifices improved the range and flatness of trajectory, while its increase had the opposite effect.

This, however, applied only to the case when the total area was increased by increasing the diameter of the orifices, and was no longer true if increase in the total area of the exhaust orifices was achieved by increasing the number of orifices. Furthermore, the tests revealed that 2" rockets with 6 exhaust orifices 0.45" in diameter had greater range and flatness than the same rockets with 5 orifices of the same diameter.[5] As Konstantinov pointed out, "the most recent experiments have proved that rockets with 6 orifices fly truer."[6]

It was therefore decided to increase the number of exhaust orifices in the base plates of PRZ rockets to six. A large quantity of these base plates were accordingly manufactured, but they could not be used, since the short grooved tails introduced at approximately the same time required that the number of exhaust orifices be equal to the number of grooves. This could not exceed five, if weakening of the surfaces between the grooves was to be avoided. It was therefore decided to forego the new base plates, and the old type with five exhaust orifices was used throughout the 1850's.

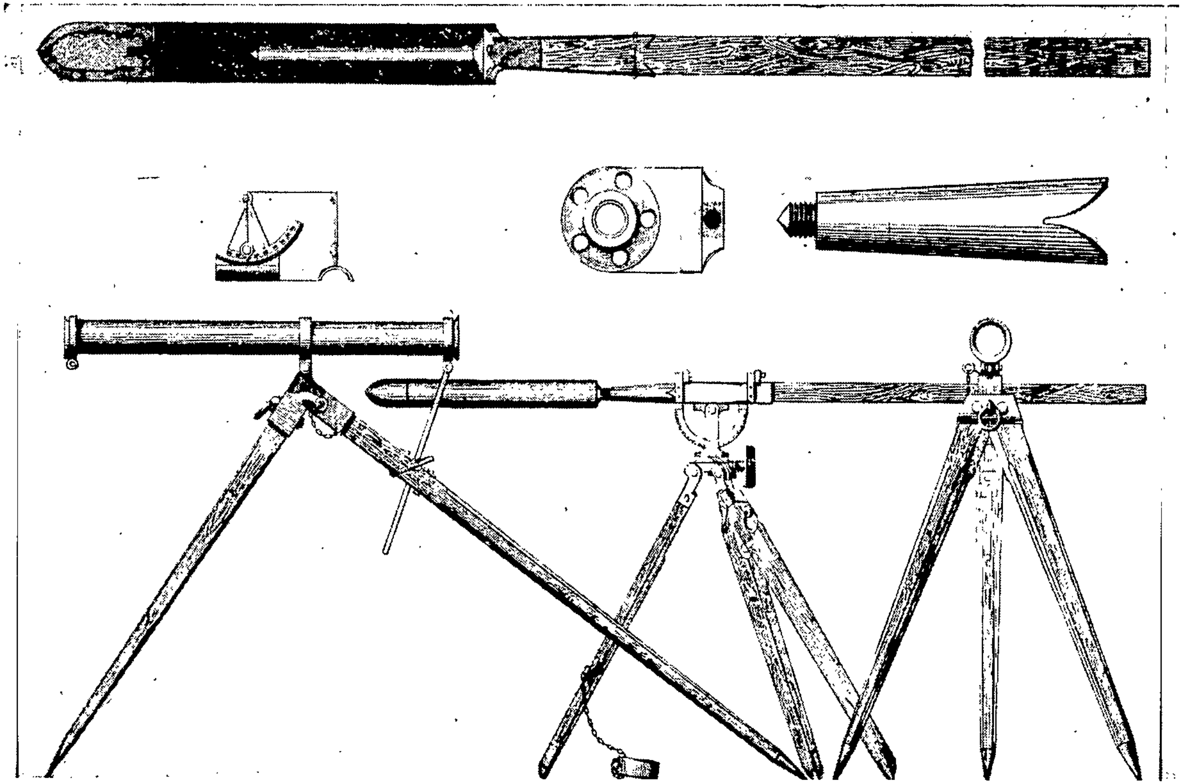


FIGURE 11. Russian military rocket (1849 model).

Thanks to Konstantinov's improvements, the quality of the military rockets produced by PRZ rose considerably. Range and accuracy were improved to some extent, and the accidents resulting from the bursting of rockets on the launchers were almost entirely eliminated. Of the 12,550 2" rockets used in actions against the enemy between 1851 and 1854, only one burst prematurely.[7]

For a long time military rockets in Russia were used almost exclusively in the Caucasus, where they were employed in thousands and performed very well. Gradually, however, interest in the use of rockets increased in other military zones. After 1851, they began to be used in the Trans-Ili region (Kirghizia), where they became part of the standard equipment of every expeditionary force.[8] After 1856 permanent rocket detachments were formed in western Siberia, and rockets were successfully used in Armenia and in the Balkans between 1853 and 1855. An attempt was made to use them during the defense of Sevastopol.

The action of Russian rocketeers at the siege and capture of Ak-Mechet in July 1853 is probably the most impressive of all. A rocket detachment under Ensign Johansen actively participated in the military actions and contributed a great deal to the capture of the fortress. During the operation both high curving rocket fire was used, against the enemy under cover, and aimed fire, to clear him out of the breaches. Demolition rockets were also used, to put the enemy's artillery out of action. Furthermore, flying detachments detailed for specific missions were also equipped with rockets.[9]

Military rockets were also successfully used in the siege of Silistria and in the battles of Babadag, Karadag, and Kyuryuk-Dara.[10] However, more widespread use of rocket armament in Russia was impeded by the fact that, in spite of the ever increasing demand for military rockets from the commanders of military districts, the central war administration, as before, underestimated rockets as a form of armament and did little to further their development. The opinion in the War Ministry for a long time was that "this projectile will annoy the troop commanders, the demand for it will thus decrease, and it will then die a natural death."[11] This attitude made it much harder to improve rocket weapons. Konstantinov wrote, "They regarded this type of projectile as having no future chance of improvement, and therefore found it worthless because of its low accuracy."[12]

In the middle of the 1850's, however, the attitude of the highest military circles in Russia began to change a little. Major reasons for this were the experience gained during the war of 1853—1856 in the use of military rockets and the successes attained in their development in other countries.

The position taken by government circles is indicative of this change. In September 1854 the War Minister V.A. Dolgorukov wrote that Nicholas I "bearing in mind the considerable successes in rocket research in Austria, England, and even France, where tests of rocket flight over very great distances were recently made, recognized the necessity of our also devoting the strictest attention to the greatest possible improvement of this type of projectile, so as not to lag behind the foreigners."[13]

After this considerably more attention was devoted to rocket armament in Russia. Military rockets were adopted in almost all military districts,

and arming of the vessels of the Russian fleet with them was begun. It was decided to construct a new improved rocket plant in southern Russia.

The introduction of military rockets into the navy was brought up as early as 1851, when Konstantinov sent to the Admiralty a "Note on the Introduction and Use of Military Rockets in the Navy" (Zapiska o vvedenii i upotreblenii boevykh raket na flote).[14] Remarking on the respects in which rockets were superior and inferior to artillery, Konstantinov pointed out the following applications which they would have in the navy:

"1. For action from rowing boats against ships and the shore.

"2. For action from shore batteries against ships.

"3. For use on land whenever the navy finds it necessary to undertake shore offenses with its own weapons.

"4. For signalling and illumination.

"5. For throwing ropes."[15]

In order to investigate in more detail the possibility of using rockets in the navy, Konstantinov proposed to conduct experiments with the 2" military rockets produced by PRZ. His proposal was discussed at a session of the Naval Study Committee[16] and was adopted, though its realization was long delayed.

Only several years later did the question begin to find a practical resolution. In 1854 the Naval Rocket Training Detachment, one of whose objectives was to familiarize the Navy with military rockets, was founded.[17] In 1855 it was decided to ship rockets to the ports of Revel, Vyborg, Sveaborg, and Kronshtadt to strengthen their defenses,[18] and in 1856 some light vessels of the Russian war fleet were equipped with rockets.

The Navy Department's demand for rockets correspondingly increased. In February 1857 the Admiralty requested PRZ to manufacture 696 military rockets for shipment to the Baltic Fleet, as follows: 180 2.5" with explosive; 180 2.5" with case-shot; 288 4" incendiary rockets; and 48 2.5" with parachutes.[19] Several hundred more rockets were ordered for experimental purposes.

In March 1858 the War Ministry decided to supply the Navy Department with 50 4" incendiary rockets annually.[20] This decision, however, evidently arose from the fact that rockets with moist propellant could not be preserved for a protracted period and were of no value, once they became unfit for use.

Throughout these years experiments on the use of rocket armament in the fleet continued. In 1857 their results formed the basis of the "Rules for the Use of Military Rockets on Rowing Boats and on Shore" (Pravila dlya upotrebleniya boevykh raket na grebnykh sudakh i na beregu), compiled by Lieutenant-Colonel Pestich.

The use of military rockets in the fleet increased steadily throughout the second half of the 1850's. The Gunpowder and Warehouse files of the Artillery Department contain many requests from the Navy Department for military rockets for the ships of the Black Sea and Caspian flotillas, for experiments, to arm ships setting out for the Amur estuary, and for other purposes.[21]

In July 1859 the Naval Study Committee met to discuss the application of military rockets in the Navy and their future development. "That our military rockets should be made well," says the Committee's Journal, "is unquestionably a matter of the greatest interest to the Navy, since

with rockets the smallest rowboats can be used for the destructive bombardment of populated cities. Moreover, this can be done at a range which makes the rowboats, because they are such small targets, inaccessible to any form of ordnance on the shore. Above all, rockets are invaluable for landings, when they can be used to illuminate the shore, give signals, and throw ropes to sinking ships. This makes it clear that the armament of our ships with good rockets to supplement their conventional artillery would improve their military qualities and heighten morale, especially on long voyages."[22]

The Naval Study Committee therefore came to the conclusion that "after necessary improvements rockets will be most useful in the Navy," and gave the Navy's annual requirements as 4400 military rockets—1100 of large caliber (4"), and 3300 of medium caliber (2.5").[23]

When military rockets were adopted by the Navy, special attention was devoted to the question of how ships on which comparatively heavy artillery could not be installed might be equipped with rockets. "The Proposal for Fitting out of Navy Vessels with Artillery Launched Objects" (Polozhenie dlya snabzheniya sudov voennogo flota predmetami, otpuskaemymi ot Artillerii), compiled in the 1860's, placed special emphasis on the following:

"To arm boats which because of the lightness of their construction cannot carry ordnance, and equally for action where needed from the boats themselves, 2.5" and 4" caliber military rockets with the appropriate paraphernalia should be supplied as follows:

Caliber	War-ships	Frig-ates	Cor-vettes	Clip-pers	Steam frigates	Steam-ships	Schoon-ers	Gun-boats	Carri-ers
	On each vessel								
2.5" military	10	10	10	10	10	10	10	10	10
" case-shot .	10	10	10	20	10	30	30	20	20
4" incendiary	10	20	30	30	10	10	10	10	10
" with 1/2 pud [18 lb] of explosive .	20	20	20	30	20	10	10	10	10
Total on each vessel	50	60	70	90	50	60	60	50	50

Note: Military rockets, as prescribed by the actual situation, should be supplied to the above-mentioned vessels in time of war, as well as to vessels which are to undertake protracted voyages; in peace-time, however, military rockets should be supplied annually, but only to training ships, for practical exercises..."[24]

During the 1850's the efficient use of military rockets was widely discussed in print.[25] Konstantinov and his supporters had to carry on a continual battle with those who opposed the use of rockets in the Russian army.

During the 1850's and 1860's Konstantinov published a great many articles on various aspects of the production and application of military rockets, and tried to take advantage of every opportunity to promote the idea of rocket armament in military circles. As early as 1855 he remarked, in a letter to Ya. I. Rostovtsev, Head of Military Schools and Academies,

that "the technological and military aspects of rocket weapons might now be made the subject of a special course, and I should be happy to be entrusted with the task of instructing the gentleman officers of the senior class in the Artillery Academy in the following subjects: general theory of design of military rockets, and methods for their construction; applications and tactics of rocket weapons; the history of rocket armament, and in particular of the military and technological aspects of its introduction and subsequent development in Russia."[26]

In 1860 Konstantinov delivered to the officers of the Mikhailovskii Artillery Academy a series of lectures based upon the many years of research and production at the Petersburg Rocket Institute. The subjects covered included rocket design and manufacture and the importance of rockets as a form of armament, tactics to be followed by rocket detachments, means for measuring the propulsive force of a rocket, and description of a rocket ballistic pendulum.

In 1861 Konstantinov's lectures on military rockets were printed in book form in Paris,[27] and were praised by scientists and technicians alike. On 10 (new style 22) July 1861 Konstantinov was a guest at the session of the Paris Academy of Sciences, where he received an expression of "thanks for his contribution."[28]

"Under the modest name of lectures," ran the citation of the French Academy, "General Konstantinov has written a detailed work on the manufacture and use of military rockets, a type of projectile which, though terrible in action, is still little known."[29]

Konstantinov's lectures were generally praised in the world press, as the following excerpts from contemporary periodicals show:

"From a scientific point of view the new work is of the greatest interest and should attract the attention of all particularly interested in the manufacture of military rockets" (Le Nord, France).[30]

"This work gives a full description of rockets which until now have been little studied. The learned general discusses the advantages of rockets as military projectiles, the benefits derived from them, their manufacture, the magnitude of their propulsive force, the improvements made in England, Austria, France, and Russia, as well as a completely new method for their production, and machines and stands of his own invention, constructed in the renowned Farcot workshop. Finally, he mentions the organization of troops using rockets. We have read this book with the greatest interest and now present a short excerpt from it in order to acquaint our readers with it" (Cosmos, France).[31]

"For the sake of science one must hope that this invaluable book will soon be translated into German... We do not know another book possessing all the features of General Konstantinov's work. It shows what rapid and powerful progress Russia is making in the development of her arts and sciences" (Militär-Zeitung, Austria).[32]

"The appearance of this work must be regarded as an important milestone in military literature, since it presents with scientific thoroughness and in generally accessible form a subject about which (excluding former works of the same author) until now only fragmentary and superficial information has been made available in print" (Allgemeine Militär-Zeitung, Prussia).[33]

"This remarkable work is of real interest not only to those soldiers who must at least be acquainted with the necessary data in order to discuss the question of rocket armament, but even to artillery technicians concerned with rocket design and production" (Artilleriiskii Zhurnal, Russia).[34]

"Military Rockets" was obviously highly regarded in a number of countries as a significant event in the development of rocketry.

At the end of the 1850's and beginning of the 1860's Konstantinov continued his experiments towards the development of better designs for military rockets, emphasizing layout, or, as he termed it, "the internal design of rockets."

The experiments performed by Konstantinov with a rocket ballistic pendulum showed that the propulsive force is developed exclusively by the combustion around the ignition channel and of a part of the blank propellant equal in thickness to the layer surrounding the ignition channel. According to Konstantinov's data the combustion of the remainder of the blank propellant made almost no contribution to the reactive force.

Konstantinov further concluded that the combustion of this part of the blank propellant, in addition to having practically no useful effect, contributed to untrue rocket flight by constantly changing the mass of the rockets and thereby shifting their center of gravity.

In an attempt to remedy this deficiency, in 1859 Konstantinov suggested replacing a part of the blank propellant *R* (Figure 12a), exceeding in thickness the layer surrounding the ignition channel, by an incombustible substance *A*, consisting of a mixture of clay and white resin. Fire was transmitted from the rocket propellant to the incombustible packing through a tube *B*, filled with a gunpowder mixture. Improved versions of these rockets became known as 1859-ers [rockets of the 1859 design].

Even preliminary experiments demonstrated the improved quality of the new rockets. They flew more stably and (at least at first) had a sure means of firing the explosive charge of the projectile. However, these rockets had one serious drawback: after prolonged storage the substance packed into the blank propellant channel became damp, often turning into a solid dirty mass which obstructed passage of fire to ignite the explosive charge. To counter this, Konstantinov suggested using a solid, rather than a moist compound for the two last fills, and the proposal was adopted. Furthermore, the diameter of the channel in the copper tube *T*, located in the incombustible mixture, was increased. These rockets came to be known as 1862-ers [rockets of the 1862 design] (Figure 12b).

More changes in rocket design were made at the end of 1862. Experiments had shown the mixture of clay and resin to be so dependable that the thickness of the layer could be considerably reduced, which would correspondingly permit lengthening of the ignition channel.

Reducing the thickness of the clay layer, however, made the forward part of the rocket lighter and thereby led to a reduction of flight accuracy. In order to compensate for the weight of the blank filling that had been removed at first a lead circle was placed above the rocket propellant, and some time later the incombustible part of the blank propellant began to be made entirely of lead.

The so-called 1863 rockets were thus developed (Figure 12c). Unlike the 1862 rockets, they had a considerably thinner layer of blank propellant,

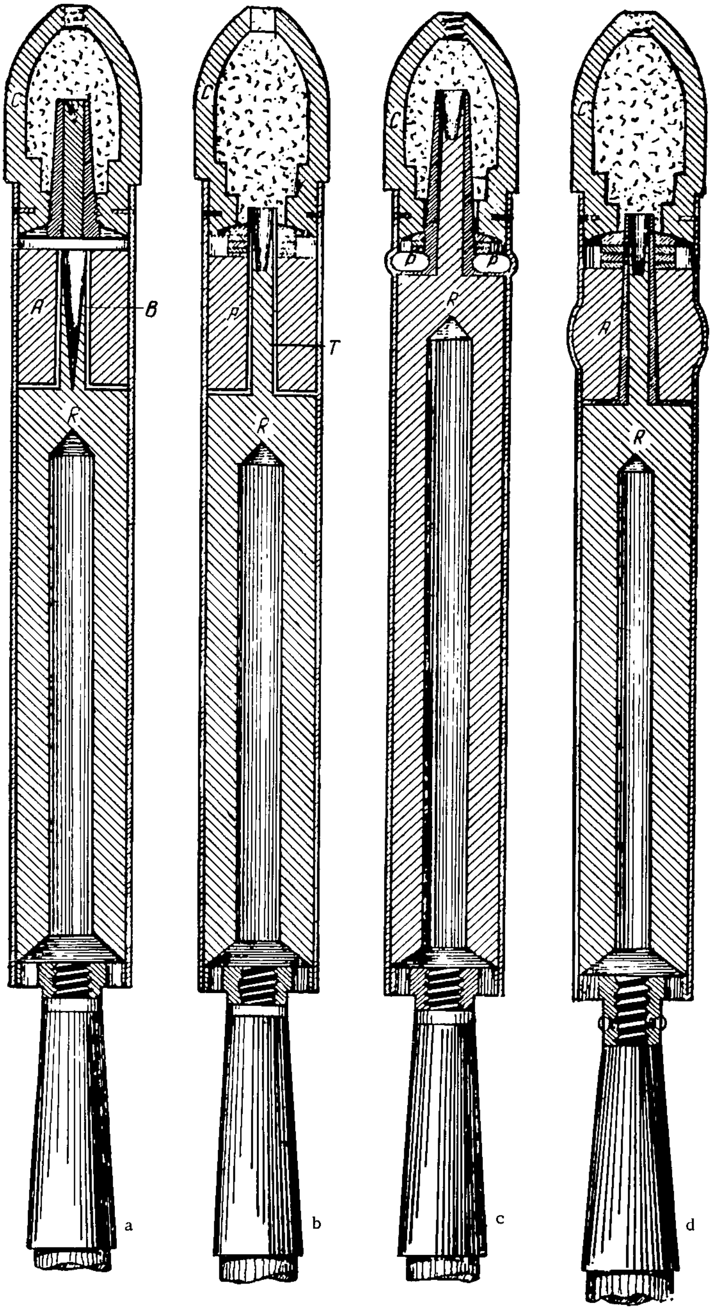


FIGURE 12. Russian 2" military rockets (1859— 1863).

a— 1859 design, b— 1862 design, c — 1863 design, d— planned design for 1867.

and its incombustible part was made of lead, rather than clay and resin soaked in turpentine. The length of the ignition channel was increased from 9.75" to 11.5".

At first the 1863 rockets were packed, as before, with moist rocket propellant, but PRZ did not abandon the idea of transition to a dry propellant consisting of a mixture of gunpowder pulp with a carbonaceous product. In 1862—1863 experiments with rockets packed with both wet and dry propellants again showed the superior accuracy and range obtained with the latter. The dry-propellant 1863 rockets, compared with the 1862 rockets, "had greater initial velocity, greater velocity throughout flight, greater flatness, greater accuracy, and finally, much longer range."[35]

It would seem that the most perfect type of rockets had been found. In order to arrive at a final conclusion as to their quality it was decided to produce 770 rockets at PRZ (385 with wet and 385 with dry propellant), including signal rockets and illuminating flares as well as military rockets (see Table 9),[36] in order to conduct final tests for purposes of comparison at Nikolaev.

TABLE 9. List of [2"] rockets prepared for tests at Nikolaev

	Number of rockets	
	1862 design (wet propellant)	1863 design (dry propellant)
Two-pounders with explosives for target fire	100	100
Ten-pounders with elongated explosives for high angle fire	50	50
Five-pounders with elongated explosives for high angle fire	50	50
Incendiaries	20	20
Long range case-shot rockets carrying 20 spherical lead rifle bullets, each weighing 7 zolotniki [about 1.1 oz]	20	20
Short range case-shot rockets carrying 35 spherical lead rifle bullets, each weighing 7 zolotniki [about 1.1 oz]	20	20
With 1/2-pud [18-lb] luminous balls	25	25
With 1/4-pud [9-lb] luminous balls	25	25
With luminous ball equipped with parachute	50	50
To be equipped with shot or Schwärmer	25	25
Total	385	385
Grand total	770	

Here, however, the insufficient technical equipment of PRZ showed itself fully since it made it impossible to obtain a uniform rocket propellant. Even in the first series of experiments conducted in Petersburg, it was revealed that in a number of cases the rocket propellant was so powerful as to result in bursting of the casings. Of 168 rockets launched, two burst on the stand, while in a third, the blank part was dislodged inside the rocket casing, though without bursting of the rocket itself.[37]

It was necessary to develop a rocket design which would not permit possible changes in the power of the rocket propellant and its destructive force to exceed a certain predetermined limit, but the impending shutdown of PRZ made this difficult. It proved possible to build and test only three rockets, all of whose specifications were as before, except that the proportion of sulfur in the propellant was increased considerably. The formula of French blasting powder (62% nitrates, 18% sulfur, 20% carbonaceous product), the weakest of those used for military rockets with a central tail, was used (see p. 65).

Experiments made for purposes of comparison showed that with these rockets the danger of an explosion was reduced, but at the cost of a reduction in range (on the average, of about 230 sagenes [537 yards]).

This concluded research on military rockets at the Petersburg Rocket Institute. Subsequently, at Nikolaev, a number of experiments were performed as a basis for the choice of designs for rockets which were then assembled at the Nikolaev Rocket Plant.

The progress made in Russian rocket research up to the beginning of the 1860's was unquestioned, but at the same period the factors which would soon result in the abandonment of rockets as military weapons began clearly to emerge. As early as the 1850's it became clear that rockets using black smoky powder could not compete with artillery in range and power. In 1851, in his "Note on the Introduction and Use of Military Rockets in the Navy," Konstantinov noted that military rockets "must cede to artillery pieces both in their inferior striking power and lesser accuracy in flight."[38] In 1863, in his "Military Rockets in Russia from the End of 1861 to the Beginning of 1863" (Boevye rakety v Rossii s kontsa 1861 g. po nachalo 1863 g.), Konstantinov stated outright: "I am far from thinking that rockets can compete with conventional artillery, but they still have an enormous field of application in cases where for whatever reasons it is impossible or inconvenient to use conventional artillery, smooth or rifled, or to perform actions impossible with artillery pieces."[39] In spite of the fact that the rockets of the 1860's were considerably better than those of the preceding decade, they were still essentially inferior to the rapidly developing artillery projectiles in both range and flight accuracy, and could serve only as supplementary weapons when for some reason it was awkward to use artillery pieces.

This idea was reflected in the reference book for artillery officers which came out during the first half of the sixties, in which it was emphasized that "rocket weapons, which constitute a powerful auxiliary to artillery, are distinguished by their mobility, adaptability to any sort of terrain, and application in every field of war."[40]

There followed a comparison of military rockets and artillery pieces, with discussion of their respective advantages and drawbacks. According to the "Reference Book," "One can list the following advantages of rockets:

"1) Rockets can be taken wherever a single infantryman has access. 2) Rocket launching requires negligible space and makes it possible to use every topographic feature for cover of both stand and crew. 3) Ease of movement and action in highly dissected terrain, with the resulting great advantage of surprise. 4) Rockets can be used in dense woods. 5) Ease of transport across rivers on very small boats, safe action being possible even during the crossing. 6) The combination of projectile and propulsive

force in rockets makes it possible to use them without any stand whatsoever, launching them from the earth, from the slope of a parapet, from an embrasure, etc. 7) When houses are occupied during a battle, the windows and balconies of every storey, as well as the roofs, can serve as convenient battle positions. 8) The speed with which rockets can be fired. Since cleaning and frequent aiming of the muzzle are dispensed with, it is possible to fire 4 shots a minute. 9) The small crews required for rocket launching, and the small number of horses required to transport military supplies for rocket batteries in the field constitute an economic and tactical advantage. 10) When necessary rockets can be destroyed in the sight of the enemy and to his detriment. 11) After rockets are used up, no awkward equipment, worthless in battle, but constituting a load which impedes movement and requires defense, is left. 12) The fact that the loss of stands is not serious, because of the ease with which they can be replaced, makes it easy to decide on sudden ventures which involve the inevitable loss of ordnance. 13) Rockets can be armed with explosive projectiles in thin-walled metal envelopes, which do not explode during the rocket's flight and penetration into the earth, but because of the low resistance to the explosion, act with all their force against the earth and thereby have a more powerful effect than hollow cast-iron artillery projectiles.

"The deficiencies of military rockets include the following: 1) The low initial velocity of rockets, by comparison with artillery projectiles, which makes it impossible to use them for the destruction of heavy objects, such as stone pavements, walls, and similar constructions. 2) As a consequence of this deficiency, rockets are less true in flight than artillery, especially in target fire; an additional reason for this in our military aimed rockets is that until now we have had only the most inadequate mechanical resources for the sound manufacture of rockets. 3) The unfitness of rockets after protracted storage is a direct consequence of this deficiency of mechanical means for their more careful construction. 4) As far as rocket transport is concerned, it can be said that if rockets constituted a greater load and volume than conventional artillery with the appurtenant military supplies, intended for exactly the same purpose as the rockets, the rockets would have the advantage of a more readily divisible load. 5) The weakness of case-shot fire from rockets can be compensated for by the speed of shooting by this projectile." [41]

Although this comparison was made by a keen advocate of rockets, [42] it only showed once again that military rockets are superior to artillery pieces only in rare instances, and must generally be held much inferior to them.

By the end of the 1860's the use of rocket weapons had been discontinued in most of the military districts of European Russia, though they continued to be used (in greatly diminished numbers) in the Caucasus and in Asiatic military districts.

A table[43] of the average ranges of military rockets will give an idea of the results attained by the Petersburg Rocket Institute.

TABLE 10. Average range of military rockets (1860's)

Type of rocket	Launching elevation, degrees	Weight of projectile*	Average range in sagenes [yards given in brackets]	
	Aimed fire			
2" military	12	2 lb 1.2 oz	450—500	[1050—1167]
" case-shot	14	2 lb 9 oz	200**	[467]
2.5" military	14	3 lb 11.1 oz	500—650	[1167—1516]
" case-shot	16	3 lb 12.9 oz	300**	[700]
4" incendiary	45	12 lb 3.6 oz	2000	[4666]
	High angle fire			
2" with 6-lb spherical grenade	45	6 lb 3.6 oz	450	[1050]
2" with 9-lb grenade	45	9 lb 10.9 oz	240	[560]
2.5" with 9-lb grenade	45	9 lb 10.9 oz	525	[1225]
2.5" with 18-lb grenade	45	21 lb	225	[525]
4" with 9-lb grenade	50	9 lb 10.9 oz	1950	[4549]
4" with 18-lb grenade	50	21 lb	850	[1983]
4" with 36-lb grenade	50	40 lb 7.2 oz	450	[1050]

* [In the Russian text the weights are given in pounds and zolotniki, the latter being equivalent to about 0.15 ounces. For the convenience of the reader these have been changed to pounds and ounces.]

** For case-shot rockets the figures given are not for range, but for the distance at which the case-shot grenades exploded.

MEANS FOR STABILIZATION OF ROCKETS

One of the most important problems confronting those working to improve military rockets was that of stability, to ensure which, rockets, like any other elongated bodies, required special devices to maintain their longitudinal axis in a certain position during flight.

The simplest means of stabilization, which was used for pyrotechnic rockets and generally gave fairly satisfactory results, was a longitudinal bar (the rocket tail). This was the form of stabilizer adopted by Kartmazov and Zasyadko, the first Russian designers of military rockets.

Subsequently rocket tails became more complicated. Realizing that the shape of the stabilizer has considerable influence on trueness of flight, designers tried to give the rocket tail a form which would permit the closest shot grouping. Furthermore, practical considerations, such as the weight of the tail, and the ease with which it could be stored, transported, and attached to the rocket, were also taken into account.

For a long time PRZ used eight-sided tails in the shape of a truncated pyramid, but four-sided prismatic tails were introduced by Konstantinov in 1851.[44] These featured a number of improvements, but were still too long, which made them awkward to store and transport.

In 1855, after becoming familiar with French military rockets brought from Sevastopol, PRZ conducted experiments with rockets having shortened tails, of the same diameter as the rocket casings.[46]

The short grooved tails were considerably lighter and not much more than half the length of the previous four-sided ones (4 ft, rather than 7 ft), which made them much easier to transport and improved their range somewhat. As a result the new tails were approved, and almost all the military

rockets produced by PRZ up to the beginning of the 1860's were fitted with them. It was soon found, however, that the grooved tails were not at all durable: they often broke during shipment, and almost entirely excluded rebounds, since on the first rebound the tails broke at the point of their attachment to the rocket.

At the beginning of the sixties, therefore, PRZ again turned to the problem of a design for rocket tails, and tested three models (Figure 13).

All three were joined to the rocket casing in exactly the same way: a part of the rocket tail, shaped like a truncated cone and covered with thin sheet iron to protect it from scorching, was inserted into the tailpipe; the remainder of the tail, of the same diameter as the casing, was not covered with iron and took one of the following three forms:

A — cylindrical with an internal void and an elongated pointed tip;

B — cylindrical with three longitudinal, progressively deeper grooves;

C — cylindrical with transverse rifling at the end.[46]

Tests showed that in both aimed and high angle fire the best results were obtained with rockets equipped with *B* tails, i.e., the conical-cylindrical type with three longitudinal grooves in the cylindrical section, becoming progressively deeper towards the rear end of the tail. On a 2" rocket, this tail was 3 feet in length.

Besides improving accuracy, these tails permitted the use of base plates with six exhaust orifices, whose advantages had been known since the early 1850's (see p. 42). As mentioned above, at that time a large quantity of base plates with six orifices was manufactured, but they could not be used because the short grooved tails introduced after 1855 required a number of orifices equal to the number of grooves, which could not exceed five except at the cost of weakening the intervening surfaces.

The *B* tails were recognized as the best and recommended for further production, but even they did not give fully satisfactory results. Rocket flight was still insufficiently true, and the closeness of shot grouping left a great deal to be desired.

Furthermore, the long rocket tails, which considerably exceeded the length of the rocket itself, were very awkward to use, transport, and store. It is not surprising therefore that most countries began to seek another means of stabilization for rockets.

In Russia the first experiments in this direction were made in the Okhtensk Gunpowder Plant in the 1840's. Signal rockets were built, with the long tails replaced either by much shorter stabilizing surfaces, which came to be known as wings, or by triangular prisms of thin cardboard (see Appendix 6, p. 182).

In all probability efforts were made to apply this type of stabilization to pyrotechnic rockets at the same time. In 1853 the "Artilleriiskii Zhurnal" carried an article entitled "Some Improvements in the Art of Fireworks" (O nekotorykh usovershenstvovaniyakh v feierverochnom iskusstve),[47] whose author reported that since 1848 he had repeatedly and successfully used rockets stabilized in flight by trapeziform wings made of doubly folded cardboard. It has not proved possible to identify the author (the article was unsigned), but, to judge by the fact that Russian measures are used throughout (foot, lot, zolotnik, arshin), one can assume that the article was original and not a translation.

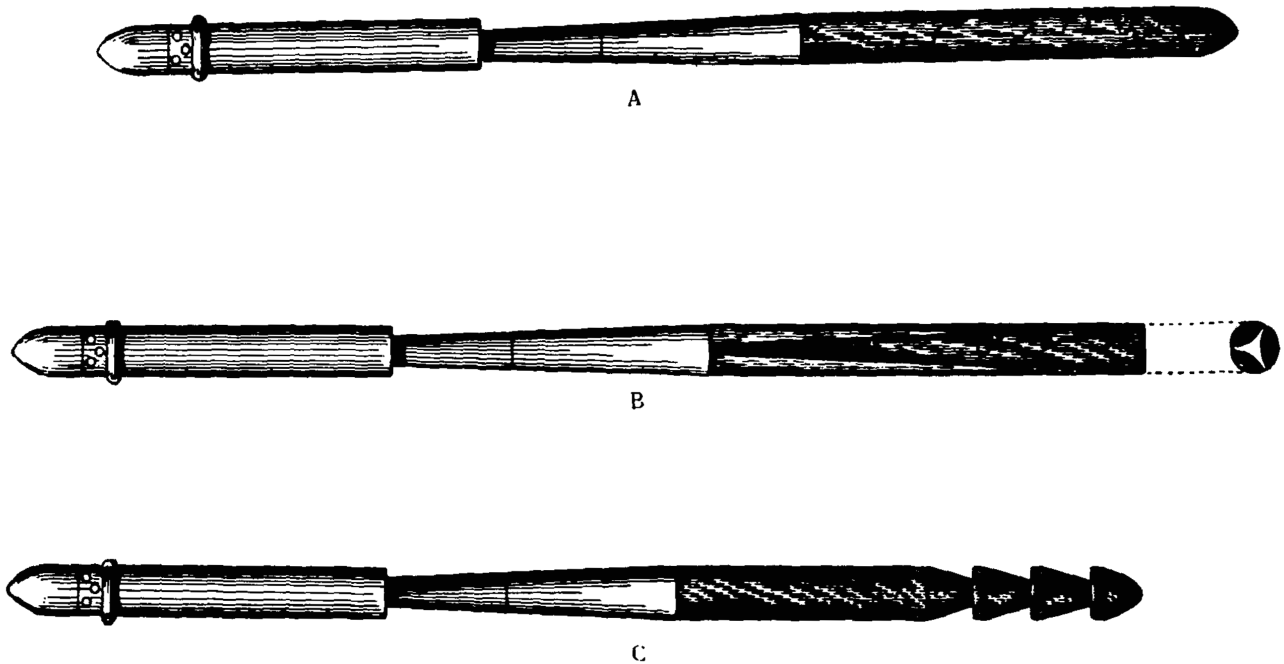


FIGURE 13. Different types of rocket tails.

The inconveniences resulting from the large dimensions of rockets were felt especially keenly in the navy, and it is therefore not surprising that the Navy Department devoted great attention to finding some other means of stabilization to replace rocket tails. In the 1850's the French Navy had introduced winged signal rockets (Figure 14a), consisting of paper casings with a cap filled with shot. A wooden prism supporting three wooden wings was fastened to the casing by wire.

During the sixties several attempts were made in Russia, as well, to replace the rocket tail by stabilizing surfaces (then called wings). In 1864 Vishnyakov, the foreman of the Kronshtadt Laboratory, proposed for testing a rocket design of his own invention, which featured wings attached to the main body by special wires. The experiments with Vishnyakov's rockets in 1864 and 1865, however, did not give positive results, and were soon discontinued.[48]

In November 1865 the Naval Technical Committee received a new proposal for the testing of rockets with stabilizing surfaces, this time submitted by Captain Kalinnikov of the Naval Artillery Detachment.[49]

Kalinnikov's rockets differed from those of Vishnyakov in the means of attaching the wings to the rocket body, but even after some changes in design winged rockets failed to give satisfactory results.

In 1866 Artilleriiskii Zhurnal published an article by Staff-Captain Skripchinskii, entitled "Parachute Rockets and Rockets with Wings" (Parashyut-rakety i rakety s kryl'yami), which described the author's experiments on rockets with stabilizing surfaces.[50]

As Skripchinskii noted, his rocket wings (Figure 14c) were made of wood, and consisted of a rod used to attach the wing to the rockets, and the wing itself, which had the form of a parallelogram. A groove was made in the edge of the rod contiguous with the rocket (see cross section along *CD*), and it had two external notches *bb*, which served to attach the wing to the rocket.

On both sides the wing had longitudinal grooves in staggered rows (see cross section along *AB*), whose number depended on the size of the wing, to lighten it. The wings were given a tapered leading edge to reduce air resistance.

Skripchinskii's article attracted the attention of rocketry experts, and the November 1867 number of "Artilleriiskii Zhurnal" carried an article by the Director of the Riga Pyrotechnic Laboratory, signed P. M., which was evidently a reply to it. This article dealt with exactly the same subjects[51] and pointed out that the Riga Pyrotechnic Laboratory, which constructed pyrotechnic rockets for sale to private parties, had been experimenting with winged rockets since 1862. Wings of various shapes and made of various materials had been tested, and the best had proved to be wooden ones having the form of a parallelogram. The dimensions of the wings are given in Table 11.

Despite the failure of the first experiments on winged rockets in 1864—1866, eagerness to do away with the clumsy rocket tails was so great that the Navy Department took the matter up again. At the beginning of 1867 experiments for the comparison of Kalinnikov's and Skripchinskii's winged rockets were held. They indicated the superiority of the former,[52] with the result that further tests were decided upon. In 1868 Kalinnikov's winged rockets were tested on the artillery training frigate "Sevastopol," but on

this occasion, too, they failed to give satisfactory results. Thereafter, experiments with winged rockets were terminated.

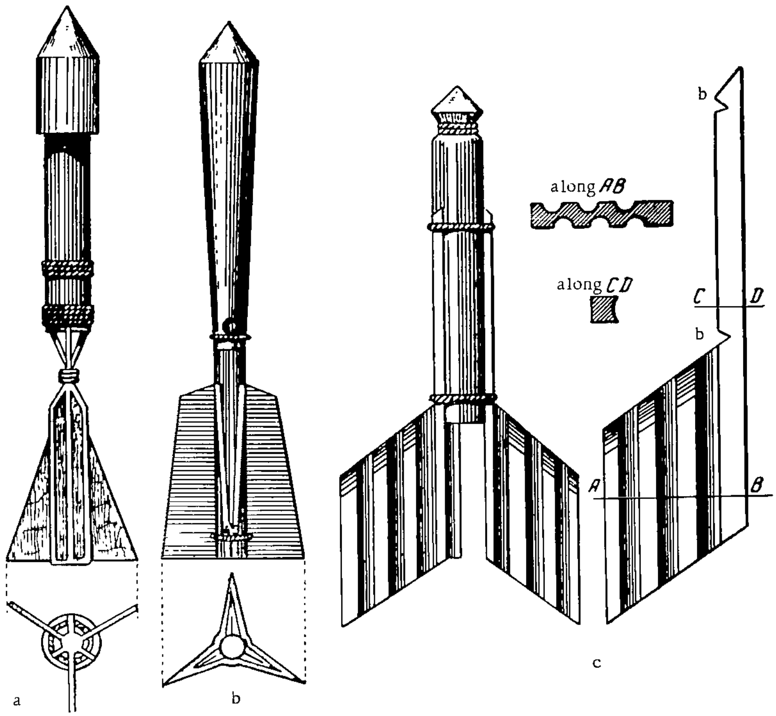


FIGURE 14. Winged rockets.

a — signal rocket adopted by the French Navy, b — rocket with cardboard wings, described by Chichinadze, c — rocket with wooden wings, as used by Skripchinskii.

In considering the various means of rocket stabilization adopted in Russia in the 19th century, one is struck by the almost total absence of

TABLE 11. Dimensions of rocket wings (in inches)

	1-pounder		1/2-pounder		1/4-pounder	
Length of wing	6.93	7.35	5.48	5.85	4.37	4.45
Width of wing	3.90	3.90	3.10	3.10	2.45	2.35
Thickness of wing	0.40	0.40	0.40	0.40	0.40	0.40
Length of rod	10.0	7.35	7.00	5.85	5.50	4.50

Note: The left half of each column refers to Skripchinskii's rockets; the right, to those built by the Riga Pyrotechnic Laboratory.

suggestions to make use of the rocket's rotation. At first glance this seems strange, the more so since this problem attracted considerable attention in other countries. In fact, according to Konstantinov, in America,

as early as 1815, experiments were made with rockets made to rotate by helical exhaust orifices in the base plate.[53]

In 1824 Parlby proposed to the British army in India the use of rockets made to rotate by special devices placed in the stream of exhaust gases. A similar means of stabilization was suggested in 1846 by the French artillery officer Goupille, whose rockets were equipped with a short helical band placed in the stream of exhaust gases. Rotation was produced by the pressure of the exhaust gases against the oblique surfaces of the helix.

In other experiments, made in France in 1831, the rockets were made to rotate by special projections inserted into slots on the inner surface of the launching tubes. The best known rotating rockets, however, were those of Hale, which were made to rotate by spiral exhaust ducts in the base plate.[54]

Hale's rockets were tested in many countries, including Russia, but again failed to give positive results.

By the middle of the 19th century, then, rocket designers seeking means of improved stabilization had already suggested the following methods for making rockets rotate:

1) fitting the outer surface of the rocket with projections and launching it from a notched tube;

2) fitting the rocket body with oblique surfaces acted upon by air currents;

3) placing such surfaces in the stream of exhaust gases;

4) making spiral exhaust orifices in the base plate.

All of these methods were known in Russia and were repeatedly recalled in Konstantinov's lecture notes and printed papers. However, no proposals for the adoption of such means of stabilization came from Russian inventors (with the exception of Lieutenant Berdyugin),[55] and no research was done on them at PRZ.

The unsuccessful tests of Hale's rockets, held in Petersburg in 1850, were a likely reason for this. The occasion for these tests was a letter from the British engineer Nottingham, who offered (naturally for appropriate remuneration) to acquaint Russians with Hale's military rockets.[56]

Nottingham remarked that Hale's rockets, while in no way inferior to, and in some ways surpassing conventional rockets with tails, were particularly distinguished by the lack of a clumsy tail, by greater compactness, and by low cost (he claimed that they cost about 30% less than Congreve rockets).

The letter was sent to the Naval Study Committee, which duly decided to test the rockets in order to gain a practical idea of their quality. Nottingham therefore came to Petersburg, bringing with him some Hale rockets manufactured in England. The experiments were performed on the Volkova field in August 1850. On the 14th, only Hale rockets were tested, and on the 17th, they were tested together with Russian rockets manufactured by PRZ.

The results obtained by the Hale rockets were extremely poor, only one of the 13 rockets launched on the first day striking a target screen placed 300 sagenes [700 yards] from the launching point. Their flight was extremely inaccurate, with a range of from 170 to 500 sagenes [397 to 1167 yards] for the first strike, and lateral deviations as much as 48 paces. Even worse results were obtained on the second day, when

the Hale rockets proved inferior to the PRZ rockets in every respect, as shown in Table 12.

TABLE 12. Comparative data obtained in tests of Hale and PRZ rockets

	Number of rockets launched	Number striking the target	Range of first strike, Sagenes [yards given in brackets]	Maximum lateral deviation, paces
Hale rockets	10	—	162—590 [378—1377]	220
PRZ rockets	10	4	72—382 [168—891]	30

The Naval Study Committee concluded from these tests that the rockets brought by Nottingham were inferior to those used by the Russian army in accuracy, and also, taking into account the difference in caliber, in range. Moreover, Hale's rockets were costlier, not cheaper, than the PRZ rockets. It is true that they were considerably more compact and convenient to transport, but as the Committee journal remarked, "this is a minor advantage, of significance only in conjunction with superior flight accuracy and effectiveness."[57] The Committee therefore decided to reject Nottingham's proposal to import Hale rockets into Russia.[58]

How were the low quality of the Hale rockets and their failure in the tests to be explained? Konstantinov, who in his papers had repeatedly considered the possibility of replacing rocket tails by other means of stabilization, gave considerable attention to these questions. After analyzing the results of the experiments, he concluded that the major deficiency of Hale's rockets was "the difficulty in obtaining fully developed rotation before the rocket began to advance," while "for the rotational motion to increase the accuracy of the projectile's translational motion, it must be set up about a certain axis tangent to the trajectory, and must be fully developed before the axis of rotation ceases to be supported."[59] Konstantinov pointed out that communication of additional rotary momentum to a rocket in flight can change the position of the longitudinal axis and can thus be "a new source of inaccuracy and straying in flight."[60]

Furthermore, all these means of imparting rotation to the rocket decreased the energy of its translational motion, which led to a corresponding decrease of range.

"These reasons alone," wrote Konstantinov in 1860, "are enough to urge abandonment of the idea of using rotational movement to improve the accuracy of rocket flight, but to them must be added the necessity of using a very heavy and complicated launching stand, which would destroy the principal advantage of these rockets — the ease with which they can be transported."[61]

The negative attitude of Russian rocket designers towards stabilization by rotation is therefore readily understood. Only in the middle of the sixties did Konstantinov alter his views, and then only to the extent of saying that first priority should be given to the production of military rockets with tails, testing of rotating rockets clearly being of minor importance.

FIRST ATTEMPTS TO LAY THE THEORETICAL FOUNDATIONS FOR ROCKETRY

Konstantinov's great service to the development of rocket engineering in Russia was in making the first attempt at a scientific approach to rocket design and production.

In some countries work on a theory of rocket motion had begun as early as the first quarter of the 19th century. Interest in the subject arose from the widespread use of rockets for military purposes in most of Europe, but this early work was rather abstract in character, full of errors and inaccuracies, was not applied to any practical purpose, and had absolutely no influence on the contemporary development of rocketry.[62]

The first attempt to create a theory of rocket motion was made by the British artilleryman W. Moore,[63] who examined a number of special problems, with and without taking into account the resistance of the medium.

At first Moore attempted to derive the differential equations of motion of the center of inertia of the rocket along the vertical, to obtain a formula for the velocity of the center of mass of a rocket launched at an angle to the horizon, to determine the trajectory followed by the center of mass and its velocity at an arbitrary point of the trajectory, and finally, to determine the range of a rocket, if the launching elevation and the time for which the propellant burns are given.

However, he oversimplified the problem by completely neglecting the resistance of the medium, which is hardly admissible for comparatively high velocities, when it has a considerable effect on the accuracy of the solution.

In most of his work, therefore, Moore attempted to take into account air resistance, which was then regarded as being proportional to the square of the velocity. However, here Moore limited his investigation to the vertical motion of rockets and the question of whether the center of inertia of a rocket, moving under the influence of reactive force, gravity, and air resistance, can have constant velocity.

The next step in the development of a theory of rocket motion was taken by the French artilleryman Montgéry, who published a paper on military rockets in 1825.[64] In it he attempted the solution of a more general problem, regarding a rocket launched at an angle to the horizon as a material point affected by three forces: reactive force, gravity, and air resistance.[65]

The equations obtained by Moore and Montgéry were quite complicated and contained a number of quantities which at that time defied analytical evaluation. As a result they had no practical application.

As already pointed out, a purely empirical approach prevailed in rocketry until the middle of the 19th century. This was the period when those involved in rocket production limited themselves to the accumulation of experimental data without making the least effort at serious scientific comprehension of the factors which determine the quality and characteristics of rockets. The individuals who sought to improve rocket armament by introducing changes in the design of military rockets generally were guided not by the results of analytical or experimental research, but by intuition and guesswork.

Such an approach to the design of military rockets made it exceedingly difficult to introduce improvements, since without scientific experimentation the basic direction to be taken in the development of rocket armament could not be correctly determined. As Konstantinov pointed out, "the unsatisfactory firing accuracy of rockets was a result of the fact that there were no means of attaining accuracy through uniformity, and no systematized search for the best rocket design. As a result, the experiments performed with this object did not sufficiently make clear the principles which had to serve as a basis for efficient rocket design." [66]

Konstantinov was aware that the creation of scientific principles of rocket engineering was prerequisite to the further development of rocketry, and he took the first steps in this direction when he laid the foundation of experimental rocket dynamics.

The choice of a starting point for his research was not accidental. Without denying the value of analytic study, and indicating the need to construct a "mathematical theory of rocket design and shooting," which he felt "would unquestionably be of great service in seeking to improve such projectiles," [67] Konstantinov regarded experiment as the basic means of perfecting rockets.

This was to be explained by the complexity of the processes taking place in the rocket. As a rule, these could only with difficulty be analyzed mathematically, and individual factors, such as the temperature of the gases in the rocket, or their pressure, taking into account a continuous exhaust flow, could not be accurately determined analytically by existing methods. Experiment was therefore the simplest and most natural way, which is why Konstantinov selected it.

One problem confronting the researchers was the complex matter of determining the force which set the rocket in motion. "The gas pressure inside the rocket and its continuous variation while gases are being formed," Konstantinov wrote in 1856, "have not yet been studied analytically with such precision as to provide a basis for improved rocket design, and the full solution of this problem seems to present insuperable difficulties. The known rate of combustion of the rocket propellant can readily be used to determine the volume of propellant consumed, the volume of the gases formed from it, and their elasticity at a known temperature, in successive intervals of time; but to determine the actual gas pressure within the rocket, one would have to know the temperature of the gases, which cannot be precisely determined. Moreover, in making the calculation one would have to consider the continuous flow of gases out of the rocket, which depends on their internal pressure and on the atmospheric pressure, the size of the gas exhaust and its reduction due to passage of the solid residue of the propellant combustion, and finally, on the influence of the forward motion of the rocket." [68]

Since the exact magnitude of the reactive force could not be found analytically, the researchers of several countries tried to solve the problem experimentally. At the pyrotechnic school in Metz (France), the propulsive force was measured by the use of a Moraine dynamometer. This consisted of a special spring composed of steel strips, which, to use Konstantinov's expression, recalled the elliptical front spring of a carriage. One of the ends of this spring rested on a steady support, while the other was subjected to the pressure of the rocket, which was placed in a special cart. This end was equipped with an indicator whose readings were plotted on the cylindrical surface of a drum rotating at constant speed.

A serious deficiency of the French dynamometer was the fact that when the pressure on the spring was decreased, its return was accompanied by oscillations which diminished the accuracy of the readings. This was unimportant when engines operating for a prolonged period, with insignificant and therefore gradual variation in pressure, were being studied. "But when the propulsive force acts for a short period," wrote Konstantinov, "with rapid pressure changes, such as occur in rockets, these machines leave a lot to be desired when it comes to the precision of the readings, since the tests are then of insufficient duration, while the changes occur too rapidly, to permit the deduction of average results."[69]

In an effort to avoid the shortcomings of Moraine's dynamometer, the Prussian Artillery Captain Hartmann proposed measuring the propulsive force of rockets by a ballistic rocket pendulum, set in motion by a rocket placed inside it.

The pendulum, made to oscillate by the reactive force of the rocket, used a special pin to trace a curve on a circle placed parallel to the plane of the pendulum's oscillation, and rotating with a known uniform velocity. Hartmann's idea was to use this curve to determine the propulsive force of the rocket, as well as its variation during combustion of the rocket propellant. However, experiments showed that the curves plotted on the rotating circle correspond to differential equations which cannot be precisely integrated. Hartmann therefore again resorted to the use of the Moraine dynamometer in his experiments.

After analysis of the various means for measuring the reactive force developed by combustion of the rocket propellant, Konstantinov concluded that the best was the rocket ballistic pendulum, with the difference that he subsituted a transmission belt for Hartmann's rotating circle, thereby obtaining much simpler equations. Professor V.A..Ankudovich (1792—1856) played an important part in the derivation of the formulas.

Konstantinov was well aware that tests performed with a ballistic pendulum gave only an approximation to the processes actually taking place inside the moving rocket, but he nonetheless contented himself with such experiments, since with existing measuring apparatus it was impossible to determine the gas pressure in the casing and the other parameters of the moving rocket.

Tests made under actual conditions (i.e., rocket launchings), in any case gave only general results, in which, as Konstantinov put it, all the particular phenomena producing the result were absorbed. It was just this — the need of an analytic research method to study one or several separate processes taking place inside the rocket — that led Konstantinov to decide on the rocket ballistic pendulum (Figure 15).

Konstantinov built his first rocket ballistic pendulum in 1846, while at the Main Gunpowder School. It consisted of a wooden parallelepiped, in which a cylinder of sheet steel was placed. One end of the cylinder was closed, while the rocket was inserted into the other, in such a way that its axis coincided with that of the cylinder. An adjusting screw was used to set up the cylinder in such a way that its axis and that of the rocket within it passed through the center of oscillation of the pendulum.

Parallel to the plane of oscillation of the pendulum was a transmission belt stretched over two cylinders, placed above each other

between the supports of the pendulum stand. The lower cylinder was geared to a flywheel, which was itself turned by two men.[70]

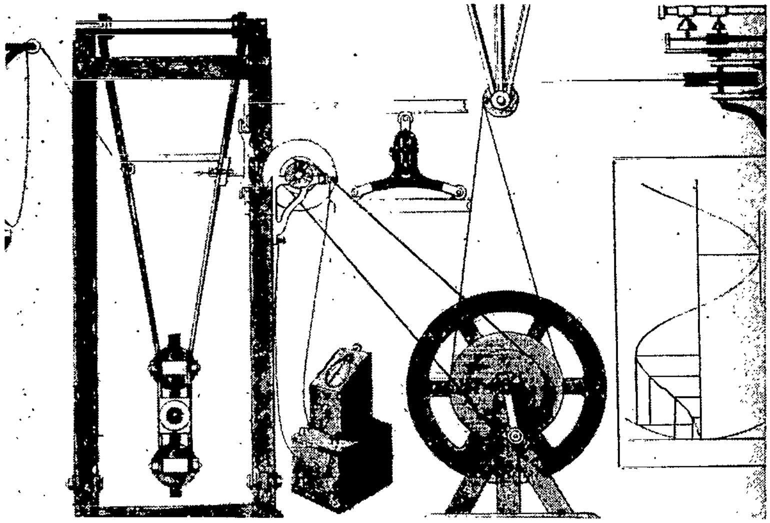


FIGURE 15. Rocket ballistic pendulum designed by K. I. Konstantinov.

Even with this comparatively simple machine Konstantinov obtained positive results. In 1848, after becoming acquainted with Konstantinov's rocket pendulum, the members of the Artillery Division of the Military Study Committee concluded that "such a pendulum really can give data for the determination both of the total propulsive force of the rocket, and of the laws governing its action."[71]

Further on, however, they commented: "In the form in which it presently exists at the Gunpowder School, the pendulum is not suitable for experiments on military rockets, because of its modus operandi; but it is highly satisfactory for research on signal rockets and flares, whose propulsive force is slight and acts over a protracted period of time."[72]

In 1849, Konstantinov began to build his second rocket ballistic pendulum, which was also suited for experiments with military rockets, in Kolpino.[73]

The second pendulum, which weighed 1780 lb, was set on a granite base. The axis of the container was 127" away from that of the pendant, and the pendulum's center of gravity was 75.4" from the axis of the pendant. The pendulum had a period of 1.73 sec.[74]

Installation and final adjustment of the second rocket pendulum, however, were very protracted, and it appears that the work was completed only at the end of 1854.[75]

A serious defect of both the first and the second rocket pendulums was the fact that the tape on which the pendulums' deviations were recorded was set in motion manually. As a result the tape's motion was not strictly

uniform, and this greatly reduced the accuracy of the readings. In an effort to overcome these deficiencies, Konstantinov proposed adoption of a special acoustic device of his own design,[76] which would limit variations in the speed of the tape.

This did to some extent mitigate this shortcoming, though it did not do away with it altogether. PRZ also failed to control the motions of the tape by some mechanical motor, which would have assured its uniformity.

In spite of this, the rocket ballistic pendulum gave a number of valuable results which were of great importance for the theory and practice of rocket engineering. In 1860 Konstantinov noted, "The rocket pendulum has given us many clues to the effect of the proportionality of the components of the rocket propellant, the internal dimensions of the ignition channel, the number and dimensions of the orifices, on the creation of the propulsive force and the character of its action; however, there have so far been too few experiments with the machine to give all the profit that can be expected from it."[77]

On the basis of his collected experimental data, Konstantinov tried to determine the optimum parameters of military rockets. By this time the major factors affecting the properties of rockets were known to include:

a) thickness of the casing walls;
b) composition of the rocket mixture;
c) dimensions of the ignition channel;
d) size and number of exhaust orifices.

The basis for determination of the thickness of casing walls was usually made the consideration that the casings should be as light as possible, but this conflicted with other demands. While the casing had to be strong enough to withstand the rather high pressure of the gases formed by combustion of the propellant, excessive increase in the thickness of its walls led to increase of its weight and raised the passive mass of the rocket. Konstantinov therefore suggested using Piober's formula[78] to determine the thickness of the walls of the rocket casing:

$$l = \frac{pd}{2T},$$

where l is the thickness of the walls in tenths of inches,
p is the maximum gas pressure in the casing, in 100 lb/in^2,
d is the internal diameter of the rocket in tenths of inches, and
T is the cohesive force of iron in 100 lb/in^2.

Of the unknowns in this formula, determination of the maximum gas pressure presented the greatest difficulty, since it depended on many factors and, as shown above, was not, in Konstantinov's day, mathematically analyzed. The gas pressure in the rocket depended first of all on the composition of the gunpowder, whose components were sulfur, nitrate, and carbon. Pyrotechnic experience had shown that an increase in the nitrate content increased the power of the rocket propellant, while an increase in the sulfur and carbon content reduced it,[79] but the best proportion of ingredients was still unknown. Furthermore, the requirements imposed on propellant for military rockets differed somewhat from those for pyrotechnic rockets. At PRZ many experiments were performed to determine the best propellant for military rockets.[80]

As a result of these experiments Konstantinov reached the following conclusions:

"a) Normal powder can be weakened by the addition of sulfur only to the point at which the ratio of the weight of sulfur to that of nitrate is 1/5. Further addition of sulfur, though it weakens the propellant as far as range and flatness of trajectory are concerned, does not diminish its explosive properties.

"b) Weakening normal powder by carbon is a completely dependable method, but not completely desirable, since addition of the carbon makes the propellant hygroscopic and more sensitive, and therefore inferior as far as the storage and transport of rockets is concerned.

"c) In general, to weaken normal powder to the degree required by military rocket design, it is best to do so by addition of sulfur, proceeding to carbon only when the limit of possible sulfur dilution has been reached.

"d) The most powerful possible rocket propellant consists of: nitrate, 72%; sulfur, 14%; carbon, 14%."[81]

Subsequently, however, Konstantinov, on the basis of the researches of the French chemist Proust, concluded that the most powerful rocket propellant was not the Austrian (72% nitrate, 14% sulfur, 14% carbon), but that using the proportions of French military gunpowder (75% nitrate, 12.5% sulfur, 12.5% carbon), and that the weakest was the French rocket propellant (62% nitrate, 18% sulfur, 20% carbon), used in long-range rockets.

TABLE 13. Various rocket propellants (mid-19th century)

	Nitrate	Sulfur	Carbon	Nitrate	Sulfur	Carbon
French military gunpowder	75	12.5	12.5	75	12.5	12.5
Austrian rocket propellant	72	14	14	75	14.5	14.5
Russian military gunpowder	75	10	15	75	10	15
Russian rocket propellant .	68	9	23	75	10	25
French rocket propellant .	62	18	20	75	21.7	24.2

Note: The left half of the table gives the percentage ratio of the components of the rocket mixture; on the right-hand side, for convenient comparison, all of the propellants are shown in terms of an identical quantity of one of the components (nitrate), and are given in parts by weight.

Konstantinov compiled a comparative table, which took in all rocket propellants, from the most powerful to the weakest (Table 13). By use of very weak propellants one could prolong somewhat the action of the reactive force, which in turn made possible an increase in range.

The depth and diameter of the ignition channel, as well as the dimensions of the exhaust orifices, greatly affected the pressure in the casing, and consequently also the magnitude of the reactive force. It had been known for a very long time that the ignition channel had considerable influence on the magnitude of the rocket's propulsive force (this was first pointed out at the beginning of the 15th century by Konrad von Kaiser), but the subject had not been sufficiently studied before the middle of the 19th century.

At the end of the 1840's Konstantinov projected,[82] and subsequently carried out,[83] a number of experiments to determine the influence of the dimensions of the ignition channel and of the area of the exhaust orifices on the magnitude of the propulsive force.

Initially (in May, 1849), Konstantinov planned to carry out three series of experiments:

1) for rockets with lateral tails and with an exhaust orifice of the same diameter as the casing;

2) for rockets with lateral tails and a base plate with an exhaust orifice of variable size;

3) for rockets with a central tail.[84]

In the first series of experiments only the dimensions of the ignition channel were varied: diameters from 0.6 to 1.4 inches, at intervals of 0.2 inches (i. e., 15.24 mm, 20.32 mm, 25.4 mm, 30.48 mm and 35.56 mm), and depth (i. e., length) of the channel from 7 to 10 inches, at intervals of 1 inch (i. e., 177.8 mm, 203.2 mm, 228.6 mm, and 254 mm). This gave 20 different combinations.

During the second series of experiments it was necessary to vary not only the dimensions of the ignition channel, but those of the exhaust orifice, whose diameter was taken equal to 0.8, 1.0, 1.2, 1.4, and 1.6 inches. To each diameter of the exhaust orifice corresponded two ignition channel diameters, one of 0.6", and the other 0.2" less than the diameter of the exhaust orifice. The depth of the ignition channel was varied as in the first series of experiments, giving a total of 40 different combinations.

In the third series the area of the exhaust orifices was taken as the maximum possible for a base plate with central tail. The channel diameter, which was determined by the diameter of the tail screw, was 0.6", and only the depth of the channel was varied, from 7" to 10" at intervals of one inch.

Subsequently Konstantinov suggested modification of these experiments to test the following three types of rockets:

A — with base plates designed by General Kozen, and total exhaust orifice area of 0.59 in^2 (381.64 mm^2);

B — with Kozen base plates, but maximum possible exhaust orifice area of 0.72 in^2 (464.8 mm^2);

C — with slats instead of base plates, giving the greatest possible exhaust orifice area (1.72 in^2, or 1110 mm^2).

In *A* and *B* rockets the diameter of the ignition channel depended on that of the tail screw and could not exceed 0.6", while in *C* rockets it could be varied as desired. In the first two types of rockets, therefore, only the depth of the ignition channel was varied, while in the third type the diameter also varied.

Here is Konstantinov's description of the order and sequence of his proposed experiments:

"In order to compare as far as possible all aspects, all *A*, *B*, and *C* rockets should have tails of identical dimensions, and the same weight of explosives. Rockets with base plates should have as standard 3.5" of blank propellant, a substantial length because in these rockets the blank propellant serves to close off the blind end. In rockets with slats, whose blind end is closed by a soldered iron ring, 1" of blank propellant

suffices. In the tests all these rockets should be target-launched from a new launcher at an angle of 20°.

"The first series of experiments should be conducted with *A*, *B*, and *C* rockets, varying the depth of the ignition channel while keeping its diameter constant at 0.6", beginning with *A* rockets and with a channel depth of 1 caliber. For each channel depth at least 3 rockets should be launched, and the depth should be increased no more than 0.25 caliber each time.

"These experiments will finally reach the extreme limit of channel depth, which we shall call *X*, and which must be less than 4.5 calibers (the present channel length).

"Continuing similarly with *B* rockets, but beginning with depth *X*, some limiting depth *y* will be obtained.

"Continuing similarly with *C* rockets, beginning with depth *y*, we shall obtain a limiting depth *Z*, whose value, to judge from experiments already performed, will be less than 10".

"The second series of experiments will have as its object tests with *C* rockets at different diameters of the ignition channel, which, to limit the number of experiments, may be taken at 0.9" and 1.2". With the 0.9" diameter channel tests should be begun with depth *Z*. This will give a limiting value *Z'*, which will serve as a starting point for tests of rockets with a 1.2" diameter channel, for which in turn *Z"* will be obtained.

"The accompanying table shows the tests as finally worked out, for five different types of rockets.

Type of rocket	*A*	*B*	*C*	*C'*	*C"*
Area of exhaust orifices, in^2 . .	0.59	0.72	1.72	1.72	1.72
Diameter of ignition channel, in . .	0.6	0.6	0.6	0.9	1.2
Depth of ignition channel	*x*	*y*	*z*	*z'*	*z"*

"It remains to compare these five types of rockets with rockets of General Kozen's design. Among these five types there will be appreciable differences, e. g., total ranges will decrease from *A* to *C* rockets, while initial velocities, and consequently flatness of trajectory for low angles of elevation and trueness of flight will increase from *A* to *C"* rockets, while high angle fire with heavy projectiles will improve from *C"* to *A* rockets, etc., although only experiment will show us to what extent these transitions will occur.

"The choice of a rocket from among the five types mentioned will in part depend on tactical considerations, though it is readily apparent that several of them will be needed to respond to the requirements of the various conditions that arise.

"Finally, study of the use of various types of projectiles, ranging from solid light explosive warheads to heavy missiles for high angle fire, will be undertaken."[85]

It has so far proved impossible to obtain information as to exactly when these experiments were performed, and with what results, but Konstantinov's repeated references to the resulting data[86] testify to their having taken place.

The results of comparative tests on the throwing of 9-lb and 18-lb explosives by rockets of various ignition channel lengths are of special interest (Table 14).[87]

TABLE 14. Results of experiments on the firing of explosives by rockets

Depth of channel, inches	Range in sagenes (yards given in parentheses)			
	Rocket with 9 lb of explosive		Rocket with 18 lb of explosive	
4.75	29	[68]	7	[16]
5.75	58	[135]	22	[51]
6.75	89	[208]	42	[98]
7.75	133	[310]	48	[110]
8.75	188	[339]	62	[145]
9.75	217	[506]	125	[292]

Note: The table shows the average ranges of three launchings. The rockets were launched at an angle of 45°.

The experiments showed that with an ignition channel of constant diameter, the gas pressure in the rocket, and therefore the magnitude of the reactive force, rose continuously as the depth of the channel was increased. When the depth was held constant, on the other hand, and the diameter increased, the gas pressure fell. This was explained by the fact that although the surface of combustion, and therefore the quantity of gases formed, increased with an increase in diameter, the volume of the channel increased as the square of the diameter. The space filled by the gas thus grew more rapidly than the amount of gas itself.

The studies of the extent to which the gas pressure and propulsive force of the rocket depend on the size of the gas exhaust orifices were also of great interest. The experiments showed that both the pressure and the propulsive force were increased, though to a different degree, by a decrease in the size of the exhaust orifice. Konstantinov noted that "the experiments have definitely established that the smaller the gas exhaust relative to the cross section of the rocket, the greater is the force of the gases against the casing; as far as the propulsive force of the rocket is concerned, it also increases as the exhaust orifices are made smaller, but to what extent has not yet been thoroughly investigated experimentally."[88]

In discussing this period, it is well to recall, however briefly, the contemporary views of the nature of reactive force.[89] In the 18th century and at the beginning of the 19th there were two points of view, each of which had its adherents and detractors.

Some scientists, including Bernoulli, Buffon, and Piober, accepted the so-called impact view, which held that reactive force arose from the separation of particles of matter. Its adherents believed that the interaction of the parent body and the particles detached from it occurred only at the moment of separation.

Others, such as Wolff, Euler, and Lagrange, regarded reactive force as a consequence of continuous full pressure on the inner walls of an envelope.

It should also be remarked that for a long time the opinion that a rocket moved by pushing away the surrounding air was widespread, though its erroneousness was demonstrated by the familiar experiment with a Segner wheel, which also rotated in a vacuum.

Konstantinov took the second view of the nature of the propulsive force of rockets, regarding the pressure of the gunpowder gases on the walls of the combustion chamber as the source of the reactive force. In his paper, "Military Rockets" (O boevykh raketakh), completed in 1856,[90] he wrote: "The gases which diffuse within the rocket create pressure in all directions, with the pressures on the sides of the rocket balancing each other. The pressure against that part of the blank propellant, however, which is directly opposite the exhaust, is not compensated and creates a force which sets the rocket in forward longitudinal motion."[91]

While regarding the reactive force as a consequence of the internal gas pressure developed by the combustion around the ignition channel, however, Konstantinov also took into account the emission of gas particles. Noting, as mentioned above, that the variation of the reactive force is not proportional to the gas pressure, and analyzing the reasons for this, Konstantinov concluded that the reactive force depended both on the pressure of the gases and their exhaust velocity. With regard to the influence of the dimensions of the exhaust orifice on the propulsive force of the rocket, he wrote: "In two rockets distinguished only by the size of their exhaust orifice, the consumption of propellant per unit of time will be the same, and since the previously formed gases must flow out of the rocket as new ones are formed. the gases must leave the rocket with the smaller exhaust orifice faster than they do the other. The momentum per unit of time of the outflowing gases, and hence that imparted to the rocket, is thus greater in the rocket with the smaller exhaust orifice."[92]

This passage is of interest not only for what it has to say about the influence of the exhaust velocity on the magnitude of the reactive force, but also because it equates the momentum of the outflowing gases with that imparted to the rocket. This fundamental assertion of rocket dynamics was clearly recognized and formulated by Konstantinov, who wrote in the paper cited above: "At every moment of the combustion of the propellant the momentum imparted to the rocket is equal to that of the outflowing gases."[93]

Although he cited several important fundamental propositions of rocket dynamics, Konstantinov failed to give them mathematical form and did not, for the reasons given above (p. 61), even attempt analytical determination of the magnitude of the propulsive force. His conclusions are nonetheless of great interest and show how close he came to solving the problem of determining the thrust of solid propellant rocket engines.

The results of the experimental research carried on at PRZ during the 1850's show that by then the fundamental relationships governing the characteristics of military rockets were known in Russia. Although the imperfect character of the experimental basis and the lack of precise measuring apparatus made it impossible to find numerical relationships and work out optimum characteristics for military rockets, the qualitative relations of the influence of such factors as the chemical composition of the rocket mixture, the fill density, the diameter and depth of the ignition channel, and the number and size of the exhaust orifices were determined with some precision.

IMPROVEMENT OF MILITARY ROCKET PRODUCTION AT THE PETERSBURG ROCKET INSTITUTE

By the beginning of the 1850's there existed a certain essentially standardized technique for the manufacture of military rockets, which was laid out in Colonel Kostyrko's manual, and comprised the following production stages:

1. Preparation of the propellant (rocket mixture).
2. Manufacture of the casings, base plates, and other metal parts required for military rockets.
3. Filling the rockets with propellant.
4. Drilling a cylindrical channel (the ignition channel) in the propellant.
5. Equipment of military rockets with projectiles.
6. Fitting the rockets with stabilizers (tails).

From a technological point of view, however, production was still at an extremely low level. Many operations were still performed manually, and in a number of cases even elementary safety engineering was not achieved. Every sort of mechanical motor was lacking at PRZ, and the entire mechanical plant comprised only shears for cutting sheet iron, presses to fill the casings, and a drill for the ignition channels. Even this scanty equipment was outmoded, having been installed in the first years of the Institute's existence, and was no longer equal to the demands made upon it.

The substantial increase in the production of military rockets therefore confronted PRZ with entirely new manufacturing problems. Semi-manual production in which hand labor of low productivity predominated had to be abandoned in favor of machine production, which would permit almost total mechanization of the laborious basic processes. Only in this way could a substantial increase in efficiency, uniformity of the finished products, and a considerable rise in production be achieved without a reduction of quality, which in hand labor depended almost entirely on the experience and craftsmanship of each individual worker.

These improvements were in fact required if the quality of rocket armament was to be raised. In order to make full use of the experimental data gathered at PRZ and from numerous field observations, a means for manufacturing rockets in no wise differing from one another was necessary.

Konstantinov attributed the greatest importance to the attainment of uniformity in military rocket production, regarding it as an unfailing condition for the improvement of rocket armament. In one of his papers on military rockets he wrote: "One of the chief conditions for the sound functioning of rockets is that they should in all respects be as far as possible identical. To this end the following points should be observed in filling the rocket with propellant:

"a) the proportion of the propellant components should not be disturbed during filling;

"b) in a given rocket the density of the propellant should everywhere be as far as possible the same;

"c) in all rockets of the same kind the density of the propellant should be as far as possible identical."[94]

Subsequently he returned to this subject, emphasizing that "the secret of military rocket production lies first in the possession of a manufacturing plant which produces perfectly uniform results, not only in the dimensions

of the various parts of the rockets, but also in the physical and chemical properties of the materials from which they are made."[95]

Finally PRZ had to face another problem, which although seemingly simpler, was still important, the more so since the actual mass production of rockets could not be considered before it was solved. Rocket production had to be made safe in order to reduce the likelihood of accidents, which were comparatively frequent before the middle of the 19th century.

In an effort to solve these problems Konstantinov drew up a number of measures designed to improve the quality of military rockets and make their production safer:

a) preparation of the rocket propellant directly from its constituent parts (sulfur, nitrates, and carbon) in the Rocket Institute itself;

b) mechanization of the manufacture of rocket casings and base plates;

c) abolition of riveted joints in favor of seamless and soldered casings;

d) improvement of the procedure for filling the casings, and substitution of a dry for a moist rocket propellant.

We shall consider these proposals separately.

Preparation of the rocket propellant directly from its constituent parts. The system adopted by the Petersburg Rocket Institute and described by Colonel Kostyrko in 1847 employed a rocket propellant of gunpowder, manufactured at the Okhtensk Gunpowder Works and modified at PRZ by an admixture of 1.2 oz carbon per pound.[96]

Spherical copper pellets placed in barrels set up horizontally were used to mix the components. The barrels were made to rotate by men protected from them by only a light fence.

This method of preparing the propellant was highly unsatisfactory and suffered from a number of deficiencies. The method of pulverizing the powder by the falling pellets was extremely dangerous to the men in charge of the barrels, since the impact of a pellet could easily cause an explosion.

In an effort to reduce the danger of preparing the rocket mixture as much as possible, Konstantinov at first proposed situating the men within an area separated from the barrels by an earth wall. Revolution counters were installed on the barrels in order to assure the most uniform rotation possible by regulation of the speed. This in turn made possible a more uniform mixture.

These measures did not rule out the danger of accidents, however, as was shown by the explosion of 1854, which entirely destroyed the shed where the barrels were located (thanks to Konstantinov's precautions those in charge of the barrels escaped injury).[97]

Furthermore, the rocket mixture obtained by the addition of carbon to gunpowder was of low quality. Konstantinov remarked that this propellant "is inferior, as far as uniformity of mixing is concerned, to that prepared directly from sulfur, nitrates, and carbon in the exact proportion required for rocket propellant."[98]

Seeking to overcome these deficiencies and obtain a uniform rocket propellant of dependable quality, Konstantinov proposed preparing it directly from its components within the Rocket Institute. He suggested using two types of barrels: copper ones to pulverise the ingredients, and oaken ones with a thick inner lining of leather to mix them.

Another of his proposals was to set the barrels up with their longitudinal axis at an angle to the axis of rotation. The mixture was then ground not by the impact of the falling pellets, but by their displacement from one end to

the other. This reduced the danger of explosions and substantially speeded up the entire operation. For example, when the older type of barrels was used to mix 72 lb of gunpowder and 8 lb of carbon, ten hours, during which the barrels made 4200 revolutions at a speed of 7 rpm, were required; with the new barrels, only 2100 revolutions sufficed, which at the same speed took only five hours.[99]

Konstantinov's proposal to prepare the rocket propellant directly from its component parts, however, was never realized. Until the day of its closing PRZ continued to produce rocket propellant by adding carbon to prepared gunpowder.

Mechanization of the manufacture of rocket casings and base plates. Originally (in the 1820's) the metallic parts of rockets were ordered from private plants and reached the Rocket Institute, where only their assembly took place, in finished form. Later the casings were produced within the Rocket Institute, which at the period in question (mid-19th century) could almost entirely meet its own needs in this area.

The manufacture of rocket casings consisted of the following operations: cutting the sheat iron, punching holes for rivets, rolling the cut rectangular sheets on a steel roller, joining them manually by cold riveting, and attaching base plates and tailpipes to the casings.

This process, however, was the least mechanized, since almost all the operations were performed manually and the only mechanical equipment employed was the shears used to cut the sheet iron. The resulting casings were of low quality.

The production of base plates and tailpipes presented considerable difficulties. Because of its poor equipment, which did not even include a steam hammer and other necessary machines, PRZ could not manufacture these metal parts itself and had to order them from private plants. This greatly complicated the situation, since it made PRZ dependent on its suppliers, while creating further technological problems. When the ready-made base plates were attached to the casings there were frequent cases of misalignment which resulted in asymmetric grouping of the orifices about the central axis.

Konstantinov tackled these difficulties with a proposal to make orifices of smaller diameter which could be expanded to the required dimensions after attachment of the base plate to the rocket. Later he concluded that it would be best to leave the drilling of the orifices altogether until after attaching the base plate to the casing.

A change in the external form of the base plates played an important role in the simplification of their manufacture. Until the 1860's base plates were convex with flared exhaust orifices. This design was dictated by a wish to protect the wooden tail from the hot flow of exhaust gases, but it greatly complicated the manufacture of the base plates. In 1860, therefore, it was decided to replace the base plates with flared orifices by flat plates "preferable for flight accuracy, ease of manufacture to the required tolerances, simplicity of installation, and cheapness."[100]

In an effort to raise efficiency and increase quality, Konstantinov devoted a great deal of attention to the improvement of casing manufacturing processes. He introduced machines to punch holes for rivets, improved shears to cut sheet metal, and a machine to manufacture the rivets.

He also attempted to mechanize such operations as rolling the rocket casings and riveting the joint, but was prevented from doing so by inadequate means. PRZ continued to perform most of these operations manually until the day it closed. Furthermore, the lack of a mechanical motor meant that manpower was also required to drive the above-mentioned machinery.

Abolition of riveted joints in favor of seamless and soldered casings. At PRZ rocket casings were manufactured by rolling rectangular iron sheets on a steel roller and cold-riveting them manually. The thickness of the riveted seam was then double that of the casing walls, which led to a displacement of the casing's center of gravity. This was aggravated by the weight of the rivets themselves.

This effect was slight in rockets with lateral tails, since the displacement of the center of gravity was partially compensated by the weight of the rocket tail attached to the side opposite the riveted seam. In rockets with a central tail, however, the ballistic qualities of the rocket were seriously affected. Furthermore, the protruding heads of the rivets complicated the filling of the casings and created the danger of an explosion. Finally, the hand manufacture of casings was laborious, inefficient, and costly.

Realizing this, Konstantinov sought to change the process and mechanize this operation, too. He wrote, "The manufacture of casings for military rockets from sheet iron by hand requires a great deal of time and is costly. It would be desirable for the industry to find means of simplifying it and producing iron pipe mechanically, with no visible joint and walls of uniform thickness on their entire circumference."[101]

As early as 1848 Konstantinov had proposed the adoption, in place of riveted rocket casings, of seamless casings manufactured in the Sestvoretsk plant by the method of Talbot and Brown.[102]

He repeated this proposal in 1850, as part of his scheme to prevent accidents at PRZ,[103] but at that time industrial production of seamless casings in Russia proved impossible, and Konstantinov had to be content with some minor changes in the production of riveted casings. These consisted of strengthening the rivet heads to some extent and introducing flush rivets for which a conical opening for the rivet heads was drilled in the inner surface of the casing.[104]

Subsequently (in the mid-fifties) Konstantinov made another effort to obtain a casing with walls of equal thickness around its entire circumference. In 1855—1856 PRZ performed a number of experiments of rockets with soldered casings. These experiments, which ran concurrently with tests of the conventional rockets produced by PRZ, showed the rockets with a smooth surface to be greatly superior in firing precision.[105]

In this instance also, however, the manufacturing process could not be altered. The Petersburg Rocket Institute went on producing riveted casings until it ceased operation.

Improvement of the procedure for filling the casings, and substitution of a dry for a moist rocket propellant. The filling of the rocket casings with propellant was one of the most complicated, dangerous, and laborious processes. The practice adopted at PRZ to facilitate this process and assure the formation of a solid dense mass (which would in turn provide even combustion) was to moisten the

propellant with wine or alcohol before filling. The procedure drawn up by Kostyrko in 1847 advocated a ratio of 0.61 to 0.91 oz dark wine per pound of gunpowder (depending on the caliber of the rocket).[106] Konstantinov adopted an alternative of moistening with 4% to 7% water or alcohol.[107]

The practice of moistening the propellant arose from the lack of sufficiently heavy presses. According to Konstantinov, the pressure needed to fill rockets with dry propellant was at least 54,000 lb/in^2 (3808.5 kg/cm^2),[108] while the existing presses of PRZ could produce a maximum of only 2880 lb/in^2 (203.12 kg/cm^2).[109] Furthermore, the practice of filling the casings with moist rocket propellant greatly reduced the danger of an explosion.

However, despite these advantages, the moistening of the propellant reduced the quality of the rockets. After termination of the filling process the propellant did not dry uniformly, with a resulting change, especially after protracted storage, in its structure. This had a considerable effect on the flight of the rockets. Moreover, the moisture in the rocket propellant had a harmful effect on the metallic parts of the rocket, which it tended to corrode.

As early as the end of the 1840's Konstantinov voiced the idea of substituting a dry propellant for the moist one, since he felt that dry propellant rockets would be superior in several respects. This was convincingly demonstrated by comparative tests performed at Tiflis in 1851.[110] In March 1852 a special disposition (No. 965)[111] introduced the use of dry propellant to fill rockets at PRZ, but the dry propellant rockets were soon found to be unreliable (there being several instances of premature bursting), and in December of the same year the disposition was revoked.[112]

The chief reason why PRZ could not fill its rockets with dry propellant in the 1850's was its lack of sufficiently heavy presses. As noted above, the pressure developed by the Institute's presses, which had been installed in the 1830's, was much lower than that required for filling, and Konstantinov was therefore temporarily forced to relinquish his progressive ideas. Subsequently he designed a hydraulic press (Figure 16) which could provide much greater fill pressure, to a maximum of 40 tons. The design was based on extensive research and preliminary study of the various types of presses in use in Austria, France, and Russia. His design, as a result, incorporated the desirable qualities of three different types. In 1860 three of the presses were manufactured at the Farcot plant in France and were highly rated by experts (in particular, the Spanish government, when ordering equipment for its newly founded rocket institute in Granada, specifically mentioned the desirability of manufacturing Konstantinov presses).

The presses built to Konstantinov's designs were delivered to Russia in 1861, but could only be used at the beginning of the 1870's in the newly founded Nikolaev Rocket Institute.

In examining Konstantinov's projects for the improvement of Russian rocket production, one is struck by the disproportion between his many proposals and those of them which were realized. Konstantinov was one of the greatest of rocket engineers, was thoroughly familiar with the history of rocketry, and attentively followed the latest developments in the field seeking to utilize every positive feature of rocket engineering anywhere in the world. He did not stop at the study and mastery of foreign

experience, but made and developed a number of proposals which found approval and became standard features of rocket engineering. He developed an original design for a rocket ballistic pendulum, designed and subsequently built from his sketches hydraulic presses to fill rocket casings, proposed a number of improvements in rocket production techniques, and introduced improvements in the design of Russian military rockets.

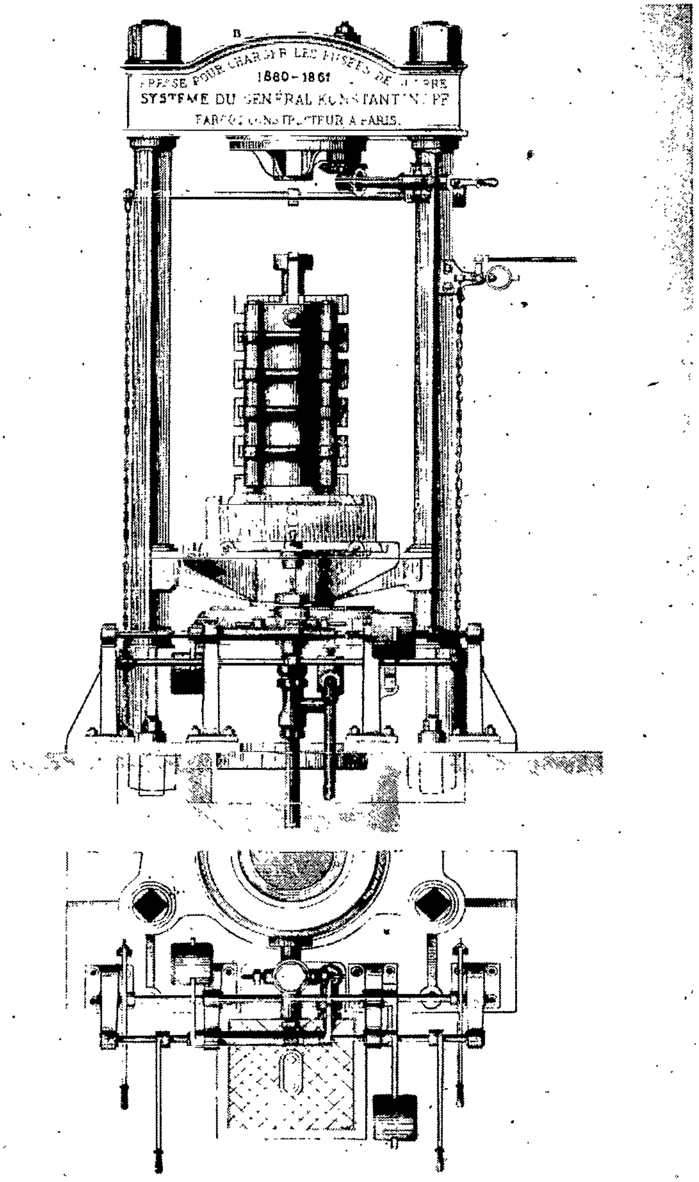


FIGURE 16. Hydraulic press designed by K. I. Konstantinov.

The production methods he advocated were as a rule the most progressive, and took into account both Russian and foreign experience in rocket engineering. Never stopping at what had already been done, never satisfied with such results as had already been obtained, Konstantinov ceaselessly sought new, more perfect solutions.

In seeking to realize his intended measures, however, Konstantinov was impeded by great obstacles, for the most part of a material character. In spite of the steadily increasing demand for military rockets from army commanders, the central war administration, as before, underestimated their value and did little to further their development.

All of Konstantinov's overtures for installation in the Rocket Institute of a mechanical motor, construction of new, more perfect presses, broadening of the Institute and introduction of necessary improvements in rocket production techniques, in a word, all his proposals aimed at expansion of military rocket production, were continually pushed aside, or their realization was postponed.

This considerably slowed the reorganization of PRZ. To realize his projects Konstantinov had to work with the comparatively small budget of 4000 silver rubles annually, allocated to PRZ by the Staff Regulation of 1850. This amount was also intended to cover maintenance of the Institute and performance of various experiments.

As Konstantinov noted in one of his articles, "after 1846 all of the Institute's means were absorbed by the preparation of urgent orders needed for war, and only with difficulty, utilizing the time left when orders were filled ahead of time, was it possible to do some research towards establishment of a general theory of rocket design and improvement of rocket construction."[113]

The reorganization of PRZ had been largely completed by the end of the 1850's, and such possibilities for improving the qualities of military rockets as existed within the Institute had been almost entirely exploited.

"During my 10-year administration," said Konstantinov, addressing the officers of the Mikhailovskii Artillery College, "all of the Institute's machines, excluding the presses, were set up on special principles devised by me, which constituted a compromise between manual and automatic mechanical operation. This was necessitated by the lack of a mechanical motor, as well as by the generally limited resources."[114]

Yet, in spite of all the improvements introduced during the preceding decade, the level of PRZ's engineering equipment remained low. Konstantinov's major problem — elimination of manual labor and its replacement by machine production -- could not be solved at the Rocket Institute, where many operations were still performed by hand. As before, there was no mechanical motor and what machines there were had to be driven by sheer muscular strength, which required the efforts of most of the personnel. The rockets were still filled by mechanical presses of obsolete design, which were insufficiently powerful to fill at the required pressures. The lack of a steam hammer and tools for accurate metal work meant that base plates with tailpipes were still ordered from private machine shops. This continued to be a source of nonuniformity in rocket production.

Further improvement of the quality of military rockets was impossible without radical changes in manufacturing techniques. A transition from semi-manual production, which consisted primarily of hand labor, to machine production, in which all major processes would be mechanized, was necessary.

Konstantinov went even further with the idea that the principal operations of rocket manufacture should be not merely mechanized, but automated. He wrote, "In pyrotechnics, if the manufacturing methods are to produce identical results, it is necessary not only to have proper machine production, but for this to be largely automatic, so that the machines will, as much as possible, replace not only the strength and craftsmanship of the workmen, but also their attention, since a slip in this area can lead to delay and failure."[115] The question therefore arose of building a new Rocket Institute, to be equipped with all the machinery needed for the manufacture of high quality rockets, "incorporating all means for rocket production with all possible improvements."[116]

ROCKET PRODUCTION AT THE NIKOLAEV ROCKET PLANT

The question of founding a new rocket institute in south Russia arose in the middle 1850's, when the Artillery Department, in connection with the elaboration of plans for the development of rocket armament in Russia, urged presentation of the measures to be taken for this end.

It was originally decided to build the new institute near Kiev, on the left bank of the Dnieper.[117] The mild climate and ready availability of cheap water power spoke in favor of this proposal.

One of the real deficiencies of the Petersburg Rocket Institute was its great dependence on climatic conditions, which extended to enforced cessation of operation for a prolonged period during the winter. It was therefore natural to want to transfer the Institute to the south where the warmer climate would make it possible to manufacture and test rockets the year round.

The choice of a power source for the machinery was of great importance. Monetary considerations were also important. The budget drawn up in 1856 set the total cost of construction at 616,000 rubles,[118] while a sum of 108,000 rubles was required to build and operate the steam engines. Originally, therefore, it was decided for the sake of economy to abandon the idea of steam engines in favor of using a river as power source, but subsequently steam engines were chosen nonetheless.

As early as 1856 Konstantinov had worked out a plan for the new rocket institute,[119] but he considered it essential, before building was begun, to familiarize himself with the latest advances in rocket production in France and other European countries which were devoting great attention to the perfecting of rocket armament. With this object, he was sent abroad in 1857, and remained away about two years. During this time he collected a great deal of material on rocket production in France and, to some extent, in Prussia, refined his plan for the new rocket institute on the basis of his knowledge of the foreign rocket institutes, and drafted

a contract with the Farcot works, near Paris, from which it was decided to order the equipment required for the new institute.[120] During 1859—1861 Konstantinov made several more visits to France to order machinery and observe its manufacture. Throughout this period a more suitable location for the new rocket institute was being sought. The environs of Chuguev, Baturin, Voznesensk, Nikolaev, and other cities of southern Russia were being considered.[121] The choice finally made was Nikolaev, as the area most suitable, in the opinion of the Artillery Department, for construction of a rocket institute and testing ground.

The machines for the new institute, built in Paris from Konstantinov's designs, were delivered to Nikolaev in November 1861.[122] Their assembly could have been proceeded with had not new doubts then arisen in the War Department as to the need for continuing development of rocket armament.[123] The desirability of building a new rocket institute again became a subject of discussion for commissions and conferences. Only a year later, in November 1862, was it finally decided to proceed with construction of the Nikolaev Rocket Institute "with the provision to pay the amount required for this purpose over a 4-year period."[121]

While the decision to build a new rocket institute in southern Russia was being made, the fate of PRZ for a long time remained uncertain. It had to supply the Army and Navy with rockets until construction of the Nikolaev Rocket Institute was finished, but there were divergent views as to what should be done with it thereafter.

Some, including Konstantinov, thought that PRZ should continue to function even after completion of the Nikolaev plant, as a source of supply in Petersburg itself for the rockets needed for the tests performed in the capital. Others felt it unnecessary to maintain two centers of rocket production, and thought it would be best to shut down PRZ.

The pace of development of military engineering, however, interfered with these plans and led to the closing of PRZ even before construction of the Nikolaev plant had been completed. The rapid improvement of artillery pieces resulted in a sharp decline of interest in military rockets. Beginning with the 1860's, most European countries ceased to employ rocket armament, and it was dismissed in many military regions of Russia.

The result of this was that, in spite of the decision to build the Nikolaev Rocket Institute, the withdrawal of military rockets in Russia actually made the situation worse, not better. Although suitable conditions for rocket production did not yet exist in the south, and the plant buildings had not even been erected, PRZ was dissolved in the summer of 1864, and its machines and equipment were sent to Nikolaev.[125]

The only actually existing center for production of military rockets in Russia had been eliminated. Meanwhile construction of the Nikolaev plant dragged on. Although it was originally scheduled for completion by the autumn of 1867, the date was repeatedly put off, and as a result production of military rockets in Russia was at a total standstill from 1864 to 1870.

It was revived only with the opening of the Nikolaev Rocket Institute at the beginning of the 1870's. The first 90 rockets, which were designated for experimental purposes, were produced in July 1871. The number of rockets produced in August was 190 (of which 90 were intended for experiments, and 100 for military purposes), while the September production

rose to 580 (including 500 for military use).[126] A total of 1500 two-inch military rockets, which were sent to Omsk, Orenburg, Krasnovodsk and Tashkent, were produced in 1871. In 1872 military rockets from Nikolaev were displayed at the Moscow Polytechnic Exhibition, and by 1873 all the detachments sent to Khiva were equipped with rockets made at Nikolaev.[127]

After the revival of military rocket production the directors of the Nikolaev Rocket Institute had to consider what form rocket armament should take in the near future. Konstantinov urged continuation of the 2" rockets, suggesting only a few superficial changes:

1. Substitution of a sulfur compound for the clayey blank incombustible propellant.
2. Replacement of the pointed projectiles and grooved tails by cylindrical explosive charges with hemispherical heads and cylindrical tails with conical tips, respectively.
3. Substitution for the moist propellant consisting of gunpowder pulp with added carbon, of a dry propellant prepared directly from its component parts.[128]

New experiments were also performed to determine the best composition for the rocket mixture. Previous experiments had led to the adoption of three different mixtures:

	Nitrates	Sulfur	Carbon
		Parts by weight	
No. 1	75	10	25
No. 2	72	14	18
No. 3	72	14	16

The experiments of June and July 1871 showed No. 1 to be too weak, while No. 3 was too strong (of 30 rockets launched, in five the base plate was blown out, while one rocket burst in leaving the stand). It was therefore decided to continue the experiments only with propellant No. 2, but further experiments, in August and September of the same year, showed that in a number of cases No. 2 was also too strong and that it had to be modified by the addition of two parts of carbon. The formula finally adopted, therefore (propellant No. 4), had 72 parts of nitrate, 14 of sulfur, and 20 of carbon.[129]

The greatest difference in the rockets produced by the Nikolaev Rocket Institute arose from its superior manufacturing techniques. It possessed the necessary lathes and equipment to cut the sheets, plane their edges, punch holes for rivets, roll casings, manufacture rivets, drill gas exhaust orifices, drill and thread the central orifice, and perform other operations.[130] Furthermore, almost all the improvements proposed by Konstantinov in the fifties and sixties were envisaged, i. e., hydraulic presses to fill the casings with rocket propellant, a steam hammer to stamp base plates, and a number of other machines actuated by a mechanical motor.

The comparatively high level of mechanization of the plant should have made possible a great increase in production. Konstantinov thought the Nikolaev Rocket Institute would produce 6000 rockets annually, with the possibility of increasing the output to 18,000 per year.[131] In practice,

however, great difficulties were encountered. For a long time the steam engine was lacking, and as a result the machines had, as before, to be driven manually. Furthermore, the hydraulic presses, which had been built as early as 1861, were found to be inefficient and to have a variety of defects, generally falling short of the demands made upon them.[132]

In the first few years, therefore, the rockets had to be built much as they had been at PRZ, and the maximum annual production did not exceed 4000. The steam engine was installed only in 1876, when it was also decided to replace the hydraulic presses by new ones.

By this time, however, the existence of the Nikolaev Rocket Institute had again been brought into question, again as a result of the general reduction of interest in military rockets. In 1875, the War Council, after asserting that military rockets were required only in extremely limited quantities, and then only in Asiatic military regions, and emphasizing that the demand for them was falling every year with the constantly rising level of artillery engineering, proposed that the Chief Artillery Administration consider whether it was even worthwhile to maintain a special rocket institute which might be better employed for the production of various types of artillery pieces.[133]

During the several months that the matter was being considered, proposals were heard to turn the Nikolaev Rocket Institute into a gunpowder or cartridge factory, to make it over into an arsenal and armorers' workshops, or even to rent it out or sell it to private parties.[134]

It is hard to say how the fate of the Nikolaev Rocket Institute would have been resolved, had it not undertaken in those years, together with the production of military rockets, that of rescue rockets, flares, and other types, which soon became its principal products.

Production of rescue rockets and flares at Nikolaev was discussed immediately after the plant opened. In 1873, at the request of the Admiralty, the Institute began experiments on the use of rockets to throw rescue lines,[135] and in 1874 the Chief Artillery Administration expressed itself in favor of conducting experiments on the use of rockets to illuminate a locality during sieges or attacks on fortresses.[136]

By 1876 the experiments had been successfully completed, and the Nikolaev Plant (as it was then often termed) began the manufacture of rescue rockets and flares for the Army and Navy. At the same time, on the initiative of Major-General Nechaev, Head of the Nikolaev Rocket Institute, experiments with fougasse rockets armed with such powerful explosives as pyroxylin were begun. Later Nechaev remarked that "in the Rocket Plant the idea of applying rockets to throw powerful explosives had existed for more than 20 years, but because of the imperfect nature of these substances it was not thought opportune to attempt it."[137] As the explosives were improved, however, the proposal acquired more reality. In 1876, after experiments performed by Navy mining officers had convinced him of the power of gun-cotton, Nechaev advocated the manufacture of pyroxylin rockets, which he held could be used for the successful bombardment, not only of buildings, artillery batteries, and troop battalions, but even of enemy iron-clads.

Beginning in 1877, the Nikolaev Rocket Plant began to produce three types of 3" pyroxylin rockets:

a) carrying a 15-lb warhead; range of 400 sagenes [933 yards] at a launching angle of 45°;

b) carrying a 10-lb warhead; range of 600 sagenes [1400 yards] (same angle);

c) carrying an 8-lb warhead; range of 700 sagenes [1633 yards] (same angle).[138]

The rockets were sent off to the Army in the Field, where, though admittedly in insignificant quantities and more as a kind of experiment, they were used against the enemy. In 1877 a total of 386 pyroxylin rockets were sent to the Army in the Field.[139] Some of these were used at the battles of Plevna, Rushchuk, and Sulin, though with no particular success.[140]

The first experience in the use of pyroxylin rockets was nonetheless felt to be positive, and in 1878 the Nikolaev Rocket Plant received a new order, this time for 800 pyroxylin rockets.[141]

Altogether, in the years 1877—1879, the Nikolaev Rocket Plant produced 22,930 rockets,[142] distributed as follows:

2" military	— 12,100
3" flares	— 8,600
3" pyroxylin	— 1,280
4" incendiary	— 450
2" incendiary	— 400
3" rescue	— 100

Once the Rocket Institute began to produce rocket flares, which were in very great demand, the question of whether it was advisable to maintain a special rocket plant was dropped, and its existence was no longer in jeopardy. The Nikolaev Rocket Plant lasted until 1910, when rocket production was taken over by the Shostensk Gunpowder Plant.

THE WITHDRAWAL OF ROCKET WEAPONS

In spite of the fact that most European countries discontinued the use of rocket weapons in the 1860's, they were produced in Russia for a considerable period thereafter.

During the seventies the Nikolaev Rocket Institute sent military rockets to the Caucasus and the Urals, as well as to Central Asia and Siberia. Rocket weapons also figured in a number of battles of the Russo-Turkish war of 1877—1878, though to a very slight extent.

By the last quarter of the 19th century a well-established type of 2" military rocket had been developed (Figure 17), and the Nikolaev Rocket Institute tooled for its production. However, as before, the troops were unfamiliar with such weapons, permanent rocket detachments no longer existed, and the rocket corps were partly composed of men ill-informed as to the structure and application of military rockets.

In 1876 the Chief Artillery Administration, observing that the information on military rockets given in the "Artillery Officers' Manual"[143] was inadequate, suggested that the Nikolaev Rocket Plant prepare a "Collection of Information on the Construction and Application of Military Rockets"

(Sbornik svedenii ob ustroistve i upotreblenii boevykh raket).[144] However, the beginning of the Russo-Turkish War in 1877 delayed execution of the project until the beginning of the 1880's, when two versions of the manual reached the Artillery Committee almost simultaneously. The first was compiled by Captain Stepanov, Head of the Workshop in the Nikolaev Rocket Plant, and the second, by Lieutenant Podruzskii of the East Siberian Artillery Brigade. Stepanov's work, the "Description of 2" Military Rockets" (Opisanie 2-kh dyuimovykh boevykh raket),[145] comprised the following sections: 1) rocket design, with a brief explanation of their fabrication; 2) packing of rockets; 3) transport of rockets; 4) receipt and shipment of rockets; 5) storage of rockets; 6) signs of deterioration in rockets; 7) means for the destruction of useless rockets; 9) rocket launching.

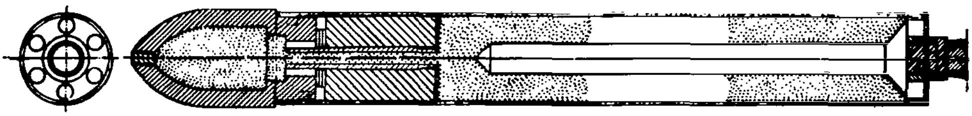


FIGURE 17. Two-inch military rocket of the 1870's.

After examining this document, the Artillery Committee in principle endorsed it with the observation that "Captain Stepanov's 'Opisanie 2-dyuimovykh boevykh raket,' written with thorough knowledge and experience of the subject, has been found to be correct, systematic and comprehensible by examination and comparison with design sketches."[146] Podruzskii's "Summary of Information on Military Rockets" (Svod svedenii o boevykh raketakh) received a much more modest evaluation. The Artillery Committee Journal remarked, "The information presented on rocket design is neither so complete nor so systematically presented as in Captain Stepanov's work; but among those items of information given in Lieutenant Podruzskii's work and lacking in that of Captain Stepanov are a scheme of regulations for the use of rockets and a list of historical facts which confirm the military value of rockets."[147] As a result it was decided to adopt Stepanov's "Description," and, after supplementing it with some of the information lacking, to send it to the appropriate military quarters. By this time, however, it was perfectly clear that there was absolutely no future for military rockets using black smoky powder. They not only failed to compete with artillery, but were even inadequate as an auxiliary to it. The low energy of smoky powder severely limited the range attainable by reaction-powered projectiles, and as a satisfactory means for stabilization of military rockets had not yet been found, they underwent considerable deviation in flight.

The same years saw considerable progress in the development of artillery, due to attainments made in metallurgy, chemistry, and ballistics. After the 1860's rifled breech-loading ordnance became very common in Russia.

As a result, the military importance of rockets gradually declined, and by the beginning of the eighties it was being asked if continued production of military rockets was worthwhile. In November 1884 troop

commanders in several regions were circularized as follows: "Owing to the unsatisfactory performance of military rockets, which cannot be compared with either field or mountain ordnance of modern design, the Artillery Committee has seen fit to question the utility of their continued manufacture and use, and feels that perhaps cessation of the production and use of military rockets is indicated."[148] The commanders were invited to submit their opinions to the War Department.

The commanders of the Caucasus, Turkestan, Omsk and Irkutsk regions, noting the poor quality of the military rockets with which their troops were equipped, urged their discontinuation, with the reservation that a few already assembled rockets be kept at hand in the event of war with the disorganized troops of the enemy.

The commander of the Amur region, however, while admitting the poor quality of the rockets and emphasizing their inferiority to artillery, felt that they were nonetheless of use, and wished to retain them among the military equipment of his troops.

On the basis of these replies and the fact that all European countries had already discontinued the use of military rockets, the Artillery Committee decided, in January 1886, to discontinue the production of military rockets in Russia[149] (see Appendix 9, pp. 190—193).

It was proposed to place the 5650 military rockets then located in the Nikolaev Rocket Plant at the disposition of the commander of the Amur troops, and to preserve the rockets included in the stores of the other Asiatic military regions in case they should be required in battle.[150]

The termination of military rocket production did not mean the end of all rocket production. The Nikolaev Rocket Institute continued to produce signal and rescue rockets and flares, and the discontinuation of military rockets turned out to be only one stage in the development of Russian rocketry. Characterized by the rise and comparatively wide dissemination, followed by the sudden decline of rocket weapons, and lasting more than 60 years, this stage left its mark in the history of Russian military engineering.

It was also of great importance in the development of Russian rocket theory and rocket engineering. This was the period in which the foundations of rocket design were laid, and the first efforts were made to create the new science of experimental rocket dynamics. The same years saw the proposal of several ideas which would determine the course of rocketry research for many years, although they were not realized until long afterwards.

The further development of solid propellant rockets was involved with the appearance of new, greatly improved forms of powder, and belongs to the second quarter of the 20th century.

NOTES

1 AIM Archive, Gunpowder Warehouse store, entry 24/3, file 438, sheet 12.

2 AIM Archive, ShGF store, entry 12, file 154, sheets 125—126.

[3] The reason for the premature bursting of rockets was clarified only much later. In the 20th century it was found that smoky powder is able to burn in parallel layers only after being compressed at very high pressures. A small fissure in the charge, which could result from manufacturing defects or from jolting or shaking in transport, etc., was sufficient to interfere with normal combustion: the charge cracked and the gases entered the fissure, increasing the combustion surface. The pressure increased sharply, and this in turn accelerated the process of gas formation, which led to an explosion. Langemak, G. E. and V. P. Glushko. Rakety, ikh ustroistvo i primenenie (The Design and Application of Rockets), p. 44. Moskva-Leningrad, 1935.

[4] AIM Archive, VUK store, entry 40, file 506, sheet 66. The experiments are also mentioned in "Report on the Activity of the Sankt-Petersburg Rocket Institute" (Otchet o deistviyakh S.-Peterburgskogo raketnogo zavedeniya v 1852 godu), 1852. — TsGVIA, store 503, entry 4, file 166, sheet 23.

[5] AIM Archive, VUK store, entry 40, file 506, sheet 29.

[6] Konstantinov, K. op. cit., p. 8.

[7] AIM Archive, ShGF store, entry 12, file 154, sheet 128.

[8] Vrochenskii. Neskol'ko slov o boevykh raketakh (A Note on Military Rockets). — Artilleriiskii Zhurnal, No. 8, section III, p. 164, 1864.

[9] Svedeniya ob upotreblenii boevykh raket pri vzyatii Ak-Mecheti (The Use of Military Rockets in the Capture of Ak-Mechet). Sankt-Peterburg, 1854.

[10] These battles are described in the articles: Ob upotreblenii boevykh raket pod Silistrieyu i pri gorode Babadage (The Use of Military Rockets at Silistria and the Town of Babadag). — Artilleriiskii Zhurnal, No. 2, section I, pp. 129—139, 1855; and Polivanov, N. Srazhenie pri Kyuryuk-Dara (The Battle of Kyuryuk-Dara). — Russkii Arkhiv, book 3, p. 287, 1904.

[11] Konstantinov, op. cit., p. 67.

[12] Ibid., p. 66.

[13] AIM Archive, ShGF store, entry 12, file 154, sheet 148.

[14] TsGAVMF, store 162, entry 1, file 285, sheets 1—2.

[15] Ibid., sheet 1 obverse.

[16] Journal of the Naval Study Committee, No. 109, 3 February, 1851. TsGAVMF, store 162, entry 1, file 285, sheets 4—6.

[17] On the activities of the Naval Rocket Training Detachment see TsGAVMF, store 165, entry 1, file 1988.

[18] Ibid., sheets 136, 148 obverse.

[19] TsGVIA, store 503, entry 4, file 1434, sheets 1—3.

[20] Ibid., file 1448, sheets 2—4.

[21] TsGVIA, store 503, entry 4, files 1435, 1455, 1467, 1468, 1471, et al.

[22] Journal of the Naval Study Committee, No. 671, 10 July, 1859. TsGVIA, store 503, entry 4, file 1114, sheet 190.

[23] Ibid., sheet 195 obverse.

[24] TsGAVMF, store 165, entry 1, file 2341, sheet 13 obverse.

[25] Artilleriiskii Zhurnal, No. 5, section II, pp. 20—59, 1856; No. 3, section II, pp. 177—210, 1857; No. 4, section II, pp. 307—341, 1857; No. 1, section II, pp. 129—142, 1858; No. 3, section II, pp. 97—121, 1858; No. 1, section II, pp. 21—29, 1859; No. 6, section IV, pp. 92—97, 1859.

[26] TsGAVMF, store 165, entry 1, file 1988, sheet 179.

[27] Constantinoff. Lectures sur les fusées de guerre. Paris, 1861. Published in Russian at Petersburg in 1864.

[28] AIM Archive, store 5, entry 4, file 660, sheet 18 obverse.

[29] Ibid., sheet 19 obverse.

[30] Quoted from the Russian translation. AIM Archive, store 5, entry 4, file 660, sheet 18.

[31] Ibid., sheets 20 obverse-21.

[32] Quoted from the Russian translation. — Russkii invalid, 9 May, 1862.

[33] Quoted from the Russian translation. — Artilleriiskii Zhurnal, No. 3, section III, p. 149, 1863.

[34] Artilleriiskii Zhurnal, No. 8, section III, pp. 161—162, 1864.

[35] Konstantinov, K. Boevye rakety v Rossii v 1867 godu (Military Rockets in Russia in 1867). — Artilleriiskii Zhurnal, No. 5, p. 849, 1867.

[36] Artilleriiskii Zhurnal, No. 5, p. 855, 1867.

[37] Ibid., pp. 856—858.

[38] TsGAVMF, store 12, entry 1, file 285, sheet 1.

[39] Artilleriiskii Zhurnal, No. 6, p. 543, 1863.

[40] Karmannaya spravochnaya knizhka dlya artilleriiskikh ofitserov (Rocket Reference Book for Artillery Officers), part II, p. 289, Sankt-Peterburg, 1863.

[41] Ibid., pp. 289—290.

[42] The author of the section "Military Rockets" (O boevykh raketakh) was N. Vrochenskii, who shared Konstantinov's views on the role of rocket armament.

[43] Karmannaya spravochnaya knizhka. . . " p. 294.

[44] AIM Archive, ShGF store, entry 12, file 109, sheet 12.

[45] Artilleriiskii Zhurnal, No. 5, section I, pp. 22—23, 1857.

[46] AIM Archive, ShGF store, entry 4, file 715, sheet 5; see also Konstantinov. Boevye rakety v Rossii s kontsa 1861 goda po nachalo 1863 g., pp. 27—29.

[47] Artilleriiskii Zhurnal, No. 6, section I, p. 449, 1853.

[48] TsGAVM, store 421, entry 2, file 39, sheet 9 obverse.

[49] Ibid., sheet 1.

[50] Artilleriiskii Zhurnal, No. 12, pp. 617—621, 1866.

[51] P. M. Parashyut-rakety i rakety s kryl'yami. — Artilleriiskii Zhurnal, No. 11, pp. 2031—2037, 1867.

[52] TsGAVMF, store 421, entry 2, file 39, sheet 1 obverse.

[53] Here and subsequently information on foreign proposals for means of imparting rotation to rockets are drawn from Konstantinov's report to the Inspector of Gunpowder Plants, of 6 September 1855. AIM Archive, ShGF store, entry 12, file 252, sheets 5—6.

[54] Journal des armes spéciales, No. 6, 1845.

[55] In 1855 Berdyugin suggested stabilizing the rocket by making it rotate about its longitudinal axis. The rotation was to be created by making the gas flow out through a spiral tube wound about the tail, and connected by thin tubes to the exhaust orifices in the base plate (AIM Archive, ShGF store, entry 12, file 252, sheet 4 obverse). The project was adversely criticized by Konstantinov, however, and put aside.

[56] Zhurnal Morskogo Uchenogo Komiteta, No. 78, 26 August 1850. AIM Archive, ShGF store, entry 12, file 37, sheet 12.

[57] AIM Archive, ShGF store, entry 12, file 37, sheet 78 obverse.

[58] Ibid., sheet 79.

[59] Konstantinov. Sposoby dlya zameny raketnykh khvostov kryl'yami ili vrashchatel'nym dvizheniem (Means for Replacing Rocket Tails by Wings or Rotational Motion). — In: "O boevykh raketakh," p. 269.

[60] Konstantinov. Primenenie vrashchatel'nogo dvizheniya k napravleniyu raket (Application of Rotational Motion to Keeping Rockets on Course). — Artilleriiskii Zhurnal, No. 6, section I, pp. 109—156, 1866.

[61] Konstantinov. O boevykh raketakh, pp. 273—274.

[62] The papers published on the theory of rocket motion in the first quarter of the 19th century were first analyzed by the Leningrad science historian A. P. Mandryk, who presented the results of his research at a combined session of the aviation and physics and mathematics sections of the Soviet National Union of Science and Engineering Historians, in Moscow, in May 1961.

[63] Moore, W. On the Motion of Rockets both in Nonresisting and Resisting Mediums. — Journal of Natural Philosophy, Chemistry, and the Arts, Vol. XXVII, pp. 276—285, November 1810; Vol. XXVIII, pp. 161—169, March 1811; Vol. XXIX, pp. 241—254, August 1811; Vol. XXX, pp. 93—94, March 1812.

[64] Montgéry. Traité des fusées de guerre, nommées autrefois rochettes et maintenant à la Congreve. Paris, 1825.

[65] The research of Moore and Montgéry is given more detailed attention in the article of Mandryk, A. P. Issledovaniya pervoi chetverti XIX veka po teorii dvizheniya raket (Research on the Theory of Rocket Motion during the First Quarter of the 19th Century) (prepared for publication in the papers of the Institute of the History of Natural Science and Engineering of the AN SSSR).

[66] Konstantinov. O boevykh raketakh, pp. 65—66. Sankt-Peterburg, 1864.

[67] Ibid., p. 98.

[68] Konstantinov. Boevye rakety (Military Rockets). — In the book: "Artilleriya. Prodolzhenie kursa, nachatogo general-leitenantom Vesselem" part II, p. 259. Sankt-Peterburg, 1857.

[69] For a description of the Moraine dynamometer and analysis of its operation see Konstantinov. O boevykh raketakh, pp. 180—181.

[70] For details of the design of Konstantinov's first rocket pendulum, see: Zhurnal Artilleriiskogo Otdeleniya Voenno-uchenogo Komiteta, No. 47, 28 Feb. 1848. AIM Archive, VUK store, entry 40, file 113, sheets 86 obverse—88 obverse.

[71] Ibid., sheets 91 obverse—92.

[72] Ibid., sheet 92.

[73] AIM Archive, VUK store, entry 40, file 113, sheet 290.

[74] AIM Archive, VUK store, entry 40, file 506, sheet 15.

[75] On this see TsGAVMF, store 165, entry 1, file 1988, sheet 160 obverse.

[76] Described in Konstantinov. O boevykh raketakh, pp. 171—172.

[77] Ibid., p. 189.

[78] On this see AIM Archive, VUK store, entry 40, file 113, sheet 177.

[79] F. Cheleev. Polnoe i podrobnoe nastavlenie..., ch. IX.

[80] AIM Archive, VUK store, entry 40, file 131, sheets 247—248.

[81] Konstantinov, K. I. Boevye rakety. In the book, "Artilleriya...," pp. 250—251.

[82] AIM Archive, VUK store, entry 40, file 131, sheets 28—34.

[83] Details of these experiments are given by Konstantinov in the book "Artilleriya...," pp. 260—261.

[84] Programma izyskanii raketnym ballisticheskim mayatnikom dlya usovershenstvovaniya 2-dyuimovykh raket (A Program of Research Using a Rocket Ballistic Pendulum for the Improvement of Two-Inch Rockets), delivered by Konstantinov on 15 May 1849, to the Artillery Section of the Military Study Committee. — AIM Archive, VUK store, entry 40, file 113, sheets 231—237.

[85] AIM Archive, VUK store, entry 40, file 131, sheets 32—34.

86 "Artilleriya. . . . ," p. 260.

87 Ibid., p. 261.

88 Ibid.

89 A more detailed analysis of the development of the major scientific views in the theory of rocket motion can be found in the dissertation of Tyulina, I. A., Razvitie mekhaniki dvizheniya tel peremennogo sostava (Development of the Mechanics of Motion of Bodies of Variable Composition), pp. 272—290. 1951.

90 This paper should not be confused with Konstantinov's book of the same name, which was published in 1864. It is the section on "Military Rockets," prepared for the book "Artilleriya. . . ," pp. 244—280. It was finished in 1856 and published separately in the same year, before the book appeared. See Konstantinov, K. O boevykh raketakh. Sankt-Peterburg, 1856.

91 "Artilleriya. . . ," p. 258.

92 Ibid., p. 261.

93 Ibid.

94 Konstantinov. Boevye rakety (Military Rockets).— In the book: "Artilleriya. . . ," p. 256.

95 Konstantinov. O boevykh raketakh, pp. 70—71. Sankt-Peterburg, 1864.

96 AIM Archive, VUK store, entry 40, file 131, sheet 243.

97 See Konstantinov, O boevykh raketakh, p. 102. Sankt-Peterburg, 1864.

98 Konstantinov. Boevye rakety.— In the book: Artilleriya. . . ," p. 252.

99 Konstantinov. O boevykh raketakh, p. 103. Sankt-Peterburg, 1864.

100 TsGVIA, store 503, entry 4, file 1186, sheet 1.

101 Konstantinov. O boevykh raketakh, p. 113. Sankt-Peterburg, 1864.

102 AIM Archive, VUK store, entry 40, file 113, sheet 185.

103 Ibid., VUK store, entry 40, file 131, sheets 9 obverse—10.

104 TsGVIA, store 503, entry 4, file 161, sheet 40 obverse.

105 AIM Archive, VUK store, entry 40, file 311, sheets 22—24 obverse. See also Artilleriiskii Zhurnal, No. 5, section I, pp. 22—33, 1957.

106 AIM Archive, VUK store, entry 40, file 131, sheet 243.

107 Konstantinov. O boevykh raketakh, p. 127. Sankt-Peterburg, 1864.

108 Ibid., p. 120.

109 Ibid., p. 121.

110 AIM Archive, VUK store, entry 40, file 131, sheets 150 obverse—151.

[111] Ibid., sheet 244 obverse.

[112] Ibid., sheets 245—245 obverse.

[113] Konstantinov. Boevye rakety.— Artilleriiskii Zhurnal, No. 3, section II, p. 205, 1857.

[114] Konstantinov. O boevykh raketakh, p. 78. Sankt-Peterburg, 1864.

[115] Konstantinov. O boevykh raketakh, p. 71. Sankt-Peterburg, 1864.

[116] Ibid., p. 67.

[117] TsGVIA, store 503, entry 4, file 1114, sheet 1.

[118] Ibid., sheet 3.

[119] See Konstantinov's report of 9 November 1856. TsGAVMF, store 165, file 1988, sheet 12 obverse.

[120] Information on Konstantinov's activity while abroad is given in his report of 17 December, 1858. TsGVIA, store 503, entry 4, file 1114, sheets 95—130.

[121] Ibid., sheets 185—188, 490—504.

[122] Konstantinov. Boevye rakety v Rossii s kontsa 1861 goda po nachalo 1863, p. 5. Sankt-Peterburg, 1863.

[123] Report of the War Department No. 9079, 15 November 1861. TsGVIA store 503, entry 4, file 1114, sheets 746—747.

[124] Kratkii obzor preobrazovanii po artillerii s 1856 po 1863 gg. (Brief Survey of the Transformations of Artillery between 1856 and 1863), p. 57. Sankt-Peterburg, 1863.

[125] AIM Archive, Gunpowder Warehouse store, entry 24/3, file 459, sheets 1—121.

[126] AIM Archive, GAU store, entry 6/1, file 145, sheets 3—8.

[127] Ibid., file 146, sheets 56 obverse—57.

[128] AIM Archive, GAU store, entry 6/1, file 123, sheet 113.

[129] The results of these experiments are given in the Artillery Committee Journal, No. 193, for 16 December 1871. AIM Archive, Artillery Committee store, entry 39/10—1, file 489, sheets 1—7.

[130] AIM Archive, GAU store, entry 8/5, file 16, sheet 42.

[131] AIM Archive, GAU store, entry 6/1, file 123, sheet 52 obverse.

[132] Ibid., file 246, sheets 2—3, 17.

[133] TsGVIA, store 504, entry 8, file 1346, sheet 2.

[134] Ibid., sheets 14—17.

[135] Ibid., sheet 11 obverse.

[136] Ibid., sheet 12.

[137] TsGVIA, store 504, entry 8, file 1348, sheet 15.

[138] Ibid., sheet 16.

[139] Ibid., sheet 17.

[140] A description of the battles involving pyroxylin rockets does not fall within the scope of the present work.

[141] TsGVIA, store 504, entry 8, file 1348, sheet 9.

[142] Ibid., file 1350, sheets 6 obverse—7.

[143] Spravochnaya knizhka dlya artilleriiskikh ofitserov (Artillery Officers' Manual), part II, pp. 289—303. Sankt-Peterburg, 1863.

[144] AIM Archive, GAU store, entry 6/1, file 261, sheet 1.

[145] AIM Archive, Artillery Committee store, entry 39/3, file 246, sheets 18—32.

[146] Artillery Committee Journal, No. 409, 22 November 1883. AIM Archive, GAU store, entry 6/1, file 261, sheet 13 obverse.

[147] Ibid., sheet 16 obverse.

[148] AIM Archive, Artillery Committee store, entry 39/3, file 246, sheet 68.

[149] Artillery Committee Journal, No. 12, 16 January 1886. TsGVIA, store 504, entry 8, file 1354, sheets 4—10.

[150] At the time some 20,000 military rockets were to be found in various storehouses: 6057 at Omsk, 3425 in the Caucasus, 2812 in Turkestan, 1061 in Amur region, 400 at Kiev, and 5650 in the Nikolaev Rocket Plant (AIM Archive, Artillery Committee store, entry 39/3, file 246, sheet 93).

Chapter IV

OTHER TYPES OF ROCKETS IN THE SECOND HALF OF THE 19TH CENTURY

PYROTECHNIC AND SIGNAL ROCKETS

As remarked above, the termination of military rocket production in Russia did not imply termination of all rocket production. At the end of the 19th century flares, as well as rescue, signal, and pyrotechnic rockets were still being produced.

The 19th century witnessed considerable progress in pyrotechnics, but the main line of fireworks development was manifested in improvement of the pyrotechnic devices and increased complexity of the figures produced. From a technical point of view 19th century firework rockets hardly differed from those of the preceding century.[1]

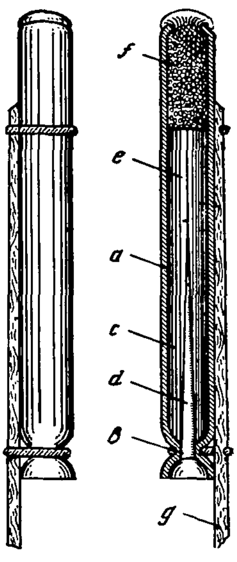


FIGURE 18. Signal rocket of the 1870's.

This was equally true of signal rockets, in whose design no essential changes were made. At the end of the 19th century signal rockets (Figure 18) consisted of a cylindrical thick-walled paper casing *a*, beneath which was a narrow orifice *b*; the internal part of the rocket above the orifice was densely packed with a force compound *c*, in which, immediately above the orifice, was a channel of conical section *d*. This was closed off above by a solid (or blind) layer of the same compound *e*, and above this layer the casing was filled with powder *f*, over which the walls were drawn together and corded. A wooden bar *g* (the rocket tail) was attached to the outside of the rocket casing.

The weight of the rocket without tail was 1 pound 32 zolotniki (536 g), and with the tail attached, 2 pounds 24 zolotniki (918 g). The signal rockets reached a maximum altitude of 400—500 sagenes [933—1167 yd], and took 4 seconds to reach it, while the time of their descent to earth was 12 seconds.[2]

RESCUE ROCKETS

During the second half of the 19th century the sphere of application of gunpowder rockets in Russia widened greatly. After the middle of the century rockets were used for rescue operations on sinking

ships, nocturnal illumination, and even (though in this area only a few attempts were made) applied to the problem of human flight.

Rockets were first used to throw ropes to sinking ships at the beginning of the 19th century, when the English Captain Trowgrouse suggested using military Congreve rockets, rather than mortars, for this purpose. The first successful trials were repeated by Dennet in England and Stiller in Prussia, and rescue rockets soon found application in other countries as well.[3]

In Russia, Konstantinov, in 1851 (see p. 45), was the first to propose use of rockets to throw a line, but the matter remained undecided throughout the fifties.

About the end of the 1850's Konstantinov began to interest himself in the ballistics of rescue rockets.[4] He arrived at the conclusion that rockets intended to throw rescue lines must have different ballistic properties from those designed to shoot projectiles. The latter required maximum velocity developed at the moment of leaving the aiming stand and briefest possible action of the propulsive force, while rescue rockets had to satisfy exactly opposite requirements, since long range was desired and breakage of the line had to be prevented. They had to have a low initial velocity, which would then increase gradually to a certain limit, in the opinion of the French inventor Tremblay, who worked on rescue rockets, about 100—200 m/sec; furthermore, the action of the propulsive force during flight had to be quite protracted.

Analysis of the means then known for reduction of a rocket's initial velocity (decrease in the depth of the ignition channel, increase in its diameter, use of a weaker rocket propellant, increase in the size of the gas exhaust orifices) led Konstantinov to the conclusion that none of them would be satisfactory in rescue rocket design, since, in addition to reducing the rocket's initial velocity, they also reduce its work potential, which in turn results in shortened range.

Konstantinov's efforts to resolve this contradiction resulted, in 1858, in an original rocket design with two channels[5] (Figure 19), the first of which (*ab*) resembled a conventional ignition channel, while the second (*cd*) was inside the blind propellant, which was simply a continuation of the propellant surrounding the first channel. The space between the two channels had to be at least as great as the thickness of the propellant surrounding the first channel.

This design made it possible to decrease the rocket's initial velocity and prolong the action of the propulsive force without reducing the rocket's work potential.[6]

During the first half of the 1860's PRZ conducted a number of comparative experiments on the shooting of rescue rockets, and after 1863 the new rockets of Konstantinov's design were in use at Russian rescue stations in the Baltic Sea.

However, this did not represent termination of the search for the best rescue rocket design, and the Admiralty continued, until the beginning of the seventies, to order large numbers of rescue rockets from England. One compelling reason for this was the sharp reduction that occurred in Russian rocket production towards the middle of the sixties. As already noted, the Petersburg Rocket Institute closed its doors in 1864, and the small pyrotechnic laboratories located in various Russian cities confined their activity to the manufacture of firework and signal rockets, as the simplest designs which did not require complicated machinery.

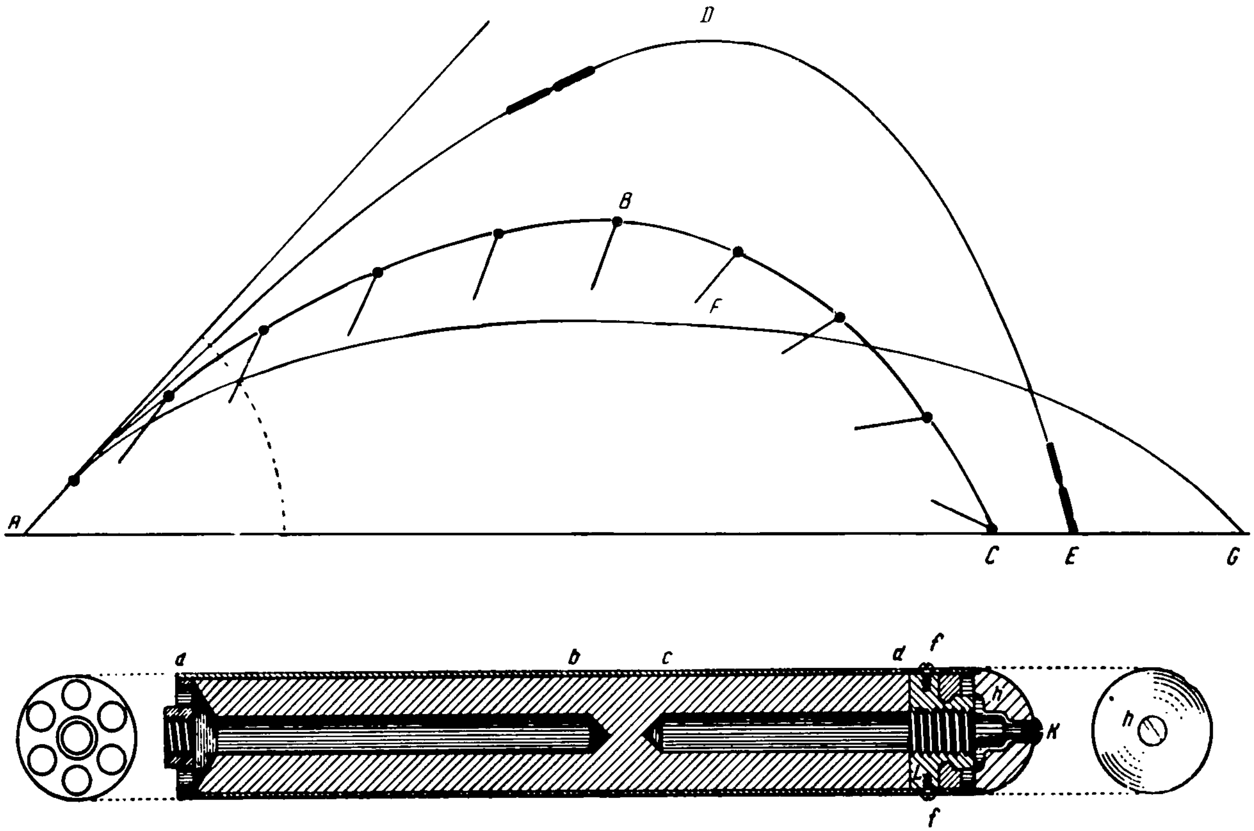


FIGURE 19. Rescue rocket designed by K. I. Konstantinov.

Production of rescue rockets could be resumed only after the Nikolaev Rocket Plant was opened. Experiments on rockets designed to throw lines were performed from 1873 to 1875, and in 1876 the Nikolaev Rocket Plant filled a Navy Department order for fifty 3" rescue rockets.[7] The number ordered in 1880 was four times as great, while the 1881 orders were for 400 rockets.[8]

By the beginning of the eighties the Russian rescue stations of the Society for Rescues at Sea were equipped exclusively with Russian rockets, whose superiority over the foreign products was felt by the directors of the Society to have been established by many years of experience in their use.[9]

ROCKET FLARES

During the last quarter of the 19th century the principal product of the Nikolaev Rocket Plant was rocket flares. The idea of using rockets with a special luminous compound to illuminate a given locality actually went back to about 1830.

In 1831 the chemist Vlasov submitted an application for "approval of certain experiments which he wished to perform on a special form of fire, of his invention, to be thrown from rockets for exposure of enemy movements, which he feels to be incomparably better, for this purpose, than the luminous balls shot from ordnance, now in use, whose effect is insignificant."[10] Vlasov was granted means for conducting his experiments, but their results remain unknown.

The question of using rockets for illumination arose again in the fifties, since the firing of luminous projectiles from artillery pieces presented great difficulties, while rockets were a highly convenient means for shooting such projectiles.

Furthermore, there was then only one means for illuminating an area on the surface of the sea (with the object of preventing the enemy from reforming his ships by night under cover of darkness): luminous balls with parachutes, which could be launched only by rockets. Rockets for this purpose were tested in 1855 at Revel, with very good results: four or five rockets, launched simultaneously, proved adequate to illuminate the entire line of coastal defences and a good part of the roadstead.[11]

On the basis of these and other experiments conducted in 1855, the artillery section of the Military Study Committee concluded that the following steps were necessary for improvement of the means of illumination used by the Russian army:

"a) In our fortresses, luminous balls should no longer be fired from ordnance, but only by military rockets;

"b) of the luminous balls presently at hand in the forts, the 1-pud [36-punders] should be thrown by 2.5" and 2" rockets, and the 0.5-pud [18-pounders], by 2" rockets;

"c.. d) rockets with luminous shot and parachute rockets should be further tested in several forts and in the Caucasus."[12]

In 1858 parachute rockets and rockets with shot were tested at the sappers' camp near Peterhof,[13] and these tests also yielded positive results.

At the end of 1858 and beginning of 1859 at Warsaw, and in the summer of 1859 during the annual camp of the Field Artillery Brigades, quite extensive experiments on the use of rockets for illumination of localities[14] were performed, and revealed a number of their deficiencies.

The research done in the Petersburg Rocket Institute established that "the best form for luminous projectiles, intended to be thrown by rockets, consists of an isosceles cylinder of strong sheet iron, covered with a lid of sheet iron, like a cartridge case, and filled with white Bengal fire, packed under pressure. The flame emerges through six circular orifices, two in the centers of the bottom and top, respectively, and four in the cylindrical surface."[15] These projectiles were launched at a high angle, gave relatively good results, and were accepted as a form of fortress artillery. The Petersburg Rocket Institute also developed designs for luminous balls with parachutes, which closely resembled the projectiles described above, except for their smaller size. The luminous ball with the folded parachute was inserted into a sheet iron casing located in the upper part of the rocket. To decrease air resistance the casing was covered above by a cardboard cone, in which the greater part of the parachute was also placed. After the rocket rose the luminous ball was thrown out of its casing by a special "dislodging charge," and the parachute, made to open by the air resistance, braked the fall of the luminous projectile.[16]

However, these rocket flares, because of their imperfections, did not find widespread use in the fifties and sixties. For a long time it remained an open question, repeatedly discussed in journals, which was the best form of illumination — artillery projectiles with a luminous compound, electrical, or rocket flares? Most experts thought searchlights the surest means, but, besides their prohibitive cost, electrical devices could not be successfully used in every situation.

"We have therefore," ran the War Department report for 1876, "turned our attention to rocket flares with shot, which have the most important advantage of carrying the illumination upwards, so that their success does not depend on the character of the locality. Experiments in the manufacture of rocket flares at the Nikolaev Rocket Institute have given successful results, and the 3" flare produced by this plant provides excellent illumination of terrain over distances of up to 450 sagenes [1050 yd], several rockets launched one after another making it possible not only to survey the enemy's works, but even to train our ordnance on the illuminated objects. These results have led to a decision to provide fortresses with 3" rocket flares, as well as searchlights."[17]

Production of rocket flares rose sharply after their acceptance for fortress defense. Over the course of five years the output rose by a factor of more than 40, from 200 in 1876 to 8850 in 1881.

The rocket flares of this period (Figure 20) consisted of an iron casing, a metal cap with shot, and a wooden rocket tail.

The design of the casing and technique of its manufacture, methods of attaching the base plate, filling of the casing with rocket propellant, drilling of the ignition channel, etc., were exactly like the corresponding operations in military rocket manufacture. The same applies to the rocket tail, which was almost identical to the stabilizers of military rockets.

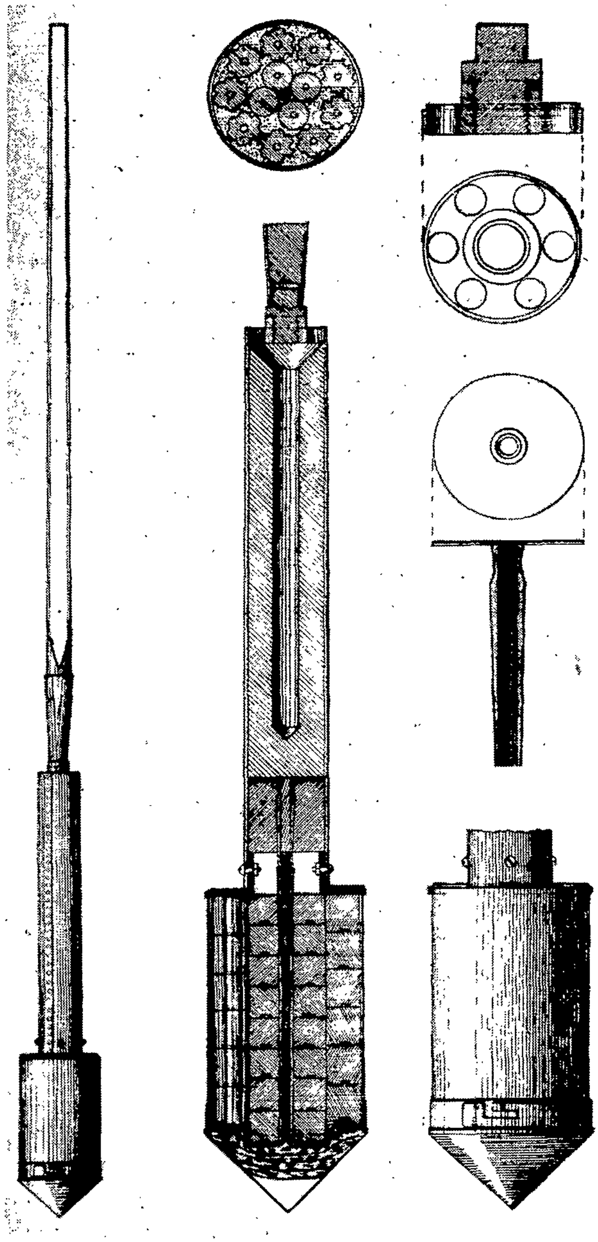


FIGURE 20. Rocket flare, end of the 19th century.

The chief difference between flares and military rockets was in the design of the head, which in flares had, instead of a projectile, a cylindrical cap with shot, 6" in diameter and 9.5" in length. The cap contained a total of 86 pellets of Bengal fire, consisting of 70% nitrate, 20% sulfur and 10% antimony, arranged around the circumference in two rows. The weight of the rocket with shot was 15 kg.

Rocket flares were fired at an angle of 45° to the horizon, and required a special launching stand. Their range was as high as 900 m. The period of combustion of the rocket propellant was so calculated that when the rocket reached the apex of its trajectory, the container of pellets was fired, and the ignited pellets formed a luminous hail which continued to burn for 15 seconds. The diameter of the surface thus illuminated was 500 m.[18]

From the end of the seventies onward the use of rocket flares became increasingly widespread. In 1879 the production of flares began to exceed that of military rockets, and in the first half of the eighties constituted roughly 85% of the entire output of the Nikolaev Rocket Plant. This resulted not only from the increased production of flares, but also from the decreased production of military rockets. For comparison production data for the seventies and eighties are given in Table 15.[19]

TABLE 15. Production of military rockets and rocket flares at the Nikolaev Rocket Plant, 1871 - 1888

Year	Rockets		Year	Rockets	
	Military	Flares		Military	Flares
1871	1500	—	1880	2000	3040
1872	3500	—	1881	1000	8850
1873	4000	—	1882	1000	5000
1874	4000	—	1883	500	3000
1875	1000	—	1884	500	3000
1876	1500	200	1885	500	3000
1877	5000	850	1886	—	3000
1878	3000	1500	1887	—	3000
1879	4500	5510	1888	—	4000

Considerable attention was devoted to the improvement of rocket flares and creation of a sufficiently large body of experts familiar with them. In the years 1880—1882 Artilleriiskii Zhurnal carried a series of articles discussing the manufacture and use of rocket flares.[20] Furthermore, while 3" rockets were being produced, 4" rockets were being tested, though the results obtained were unsatisfactory.

Notwithstanding the fact that thousands of rockets were expended in training and experiments, the total number of rockets in use for fortress armament grew steadily and stood at 27,701 on 1 January 1889. In the opinion of experts, however, this was still not sufficient to meet the growing needs of the fortresses for means of illumination.

According to the Artillery Committee, the total number of rockets in all the fortresses and siege-trains of Russia should have been 65,800.[21] It was therefore decided to increase sharply the output of rocket flares, which until the Nikolaev Rocket Plant closed down continued to be its chief product.

NOTES

1 A clear account of the development of pyrotechnics in the 19th century can be found in the following books: Nat, E. Praktika dlya pirotekhnikov ili rukovodstvo k pravil'nomu proizvedeniyu rabot, neobkhodimykh pri feierverkakh (Pyrotechnician's Handbook, or a Manual for the Proper Execution of the Necessary Preparations for the Production of Fireworks), Sankt-Peterburg, 1845; Rumyantsev, P. Teoreticheskaya i prakticheskaya pirotekhnika ili iskusstvo delat' feierverki (Theoretical and Practical Pyrotechnics, or the Art of Making Fireworks), Moskva, 1852; Matyukevich, F. Sobranie formul i retseptov sostavov poteshnoi pirotekhniki (Collection of Formulas and Mixture Recipes for Pyrotechnic Entertainments), Sankt-Peterburg, 1861; Stepanov, F. V. Pirotekhniya (kurs feierverochnogo isskustva) (Pyrotechnics (A Course in the Art of Fireworks)), Sankt-Peterburg, 1894; Tsytovich, P. Opyt ratsional'noi pirotekhniki (rukovodstvo dlya izucheniya teorii i praktiki feierverochnogo iskusstva) (Experience in Efficient Pyrotechnics (A Manual of Instruction in the Theory and Practice of the Art of Fireworks)), Sankt-Peterburg, 1894.

2 The data on signal rockets are drawn primarily from the book, "Brief Artillery Service Manual for 1877 Model Field Pieces (Kratkoe rukovodstvo artilleriiskoi sluzhby s polevymi orudiyami obraztsa 1877 goda), Section III, pp. 124—134. Sankt-Peterburg, 1878.

3 Ley, W. Rockets, Missiles and Space Travel, p. 76. New York, 1958.

4 Konstantinov's research on rescue rocket ballistics is described in his article, "Boevye rakety v Rossii s kontsa 1861 g. po nachalo 1863, Artilleriiskii Zhurnal, No. 5, section III, pp. 352 — 413, and No. 6, section III, pp. 484—543, 1863. A reprint of the article was made later in the same year. Konstantinov considered the applications of rescue rockets in greater detail in his "Application des fusées au jet des amares de sauvetage," St. Petersbourg, 1863.

5 Konstantinov's report No. 57, 25 December 1858. — In: Konstantinov, Boevye rakety v Rossii s kontsa 1861 po 1863, p. 91. Sankt-Peterburg, 1863.

6 Some non-Russian works on the history of rocketry report that Konstantinov's design for a bi-channeled rescue rocket was preceded by that of the British Colonel Boxer (1855). See for example Ley, W. Rockets, Missiles and Space Travel, pp. 76— 77. New York, 1958.

7 AIM Archive, GAU store, entry 8/5, file 16, sheet 219.

8 TsGVIA, store 504, entry 8, file 1352, sheet 1.

9 Ibid., file 486, sheet 1.

10 AIM Archive, GAU store, entry 3/2, file 166, sheet 1.

11 Artilleriiskii Zhurnal, No. 4, section II, p. 316, 1857.

12 Rezul'taty proizvedennykh Artilleriiskim otdeleniem opytov nad brosaniem v nochnoe vremya svetyashchikh yader pomoshch'yu boevykh raket (Results of the Experiments on Throwing Balls by Military Rockets at Night, Conducted by the Artillery Section). — Artilleriiskii Zhurnal, No. 1, section I, p. 69, 1856.

13 Artilleriiskii Zhurnal, No. 1, section II, pp. 21—22, 1859.

14 For further details of these experiments see Reintal', R. "Throwing Luminous Projectiles by Means of Military Rockets" (Metanie svetyashchikh snaryadov posredstvom boevykh raket).— Artilleriiskii Zhurnal, No. 7, section II, pp. 493—532, 1860.

15 Konstantinov. O boevykh raketakh, p. 210. Sankt-Peterburg, 1864.

16 Ibid., pp. 212—213.

17 Vsepoddaneishii otchet o deistviyakh voennogo ministerstva za 1876 god. (Most Thorough Report on the Activities of the War Department for 1876), pp. 46—48. Sankt-Peterburg, 1878.

18 The information on rocket flares is based on "Description of 3" Rocket Flares" (Opisanie svetyashchikh 3-dm. raket).— Artilleriiskii Zhurnal, No. 5, pp. 277—292, 1881, and that on the radius of the illuminated surface and the length of combustion of the pellets is borrowed from "Officers' and Civil Servants' Manual" (Spravochnaya kniga dlya ofitserov i chinovnikov), pp. 593—596, Moskva, 1879.

19 These data are drawn from the official reports of the Chief Artillery Administration for the years in question.

20 Pravila upotrebleniya 3-dm. raket pri proizvodstve strel'by iz oruzhiya (Rules for the Use of 3" Rockets in Firing from a Gun).— Artilleriiskii Zhurnal, No. 12, pp. 1260—1273; Obuchenie nizhnikh chinov pri svetyashchikh raketakh (Instruction on Luminous Rockets for the Lower Ranks). — Artilleriiskii Zhurnal, No. 2, pp. 12 — 14, 1881; Opisanie svetyashchikh 3-dm. raket (Description of Luminous 3" Rockets).— Artilleriiskii Zhurnal, No. 5, pp. 277—292, 1881; Prichiny i sposoby ustraneniya prezhdevremennogo razryva svetyashchikh raket (Causes and Methods of Eliminating Premature Explosions of Luminous Rockets).— Artilleriiskii Zhurnal, No. 5, pp. 64—66, 1882; also No. 10, pp. 204—207.

21 TsGVIA, store 504, entry 8, file 1876, sheet 56 obverse.

Chapter V

ATTEMPTS TO POWER AIRCRAFT BY SOLID PROPELLANT ROCKETS

From the middle of the 19th century onwards repeated proposals were made in Russia to use the energy of solid propellant rockets for propulsion of aerostats and other aircraft both lighter and heavier than air.

The idea of building aircraft operating on a reaction principle is several centuries old. As early as the turn of the 15th century Giovanni Fontana, Rector of the University of Padua, suggested using reaction engines — gunpowder rockets — to move artificial birds through the air. Several historians assert that at about the same period "flying crows and dragons", also propelled by gunpowder rockets, were being built in eastern countries.[1]

Proposals to apply the reaction principle to manned flight became increasingly frequent after the turn of the 19th century. By this time, the problem of raising man into the air in lighter-than-air craft, i. e., aerostats, had already been resolved, but no means of flight control had yet been found.

In 1784 the two French inventors Miolan and Jannine devised a means for control of aerostats through the reaction of the air flowing out through an opening in the shell of the aerostat. For experimental purposes they built a large balloon, but they did not succeed in flight-testing it because it burst and burned while being filled with warm air.

In 1831 an unknown Italian also developed a plan for a lighter-than-air reaction craft — a balloon propelled by a rocket cluster.

Other schemes for reaction aircraft, involving the most various sources of energy (compressed air, steam or alcohol vapor, liquid hydrocarbons, nitroglycerine, etc.) were put forward, but the present work, which is devoted to the history of solid propellant rockets, will be concerned only with those designs using as their source of energy gases formed by the combustion of gunpowder compounds.[2]

In 1849 the Russian military engineer I. I. Treteskii (1821—1895) developed designs for three aircraft, one of which was intended to run on power developed by the reaction of gunpowder gases. After commenting on the failure of previous attempts to control the flight of aerostats by means "analogous to the flight of birds and the swimming of fish," Treteskii wrote, " . . . as a basis for the control of aerostats it is far more convenient to take the natural law which causes the recoil of artillery pieces and the movement of a rocket, respectively, when they are fired. This effect is to be explained by the gas pressure against the surfaces respectively opposite the mouth of the gun and the rocket exhaust orifice, since this pressure is not balanced by an opposite pressure, which is

eliminated by the unimpeded outflow of the gases through the mouth or exhaust orifice."[3] In his unpublished paper "Means for the Control of Aerostats" (O sposobakh upravlyat' aerostatami), which he presented in May 1849 to M.S. Vorontsov, Commander-in-Chief of the Independent Caucasus Corps,[4] he wrote, "If, on the basis of this law, one were to build a vessel in which some elastic fluid, such as steam, gas, or compressed air, were constantly being formed, so that the pressure of the fluid would give rise to a force against the corresponding part of the vessel wall, upon its outflow through the opening of the vessel, the vessel would evidently be propelled forward like a rocket, drawing behind it a ship with balloon, provided this force P overcomes the resistance R'' of the ship and balloon when they have a given velocity V, and as long as the sum of these resistances acts symmetrically with respect to the point of application of the propulsive force, so that the motion of balloon and ship is uniform and does not deviate from the given directing force."[5]

Treteskii's idea was dismissed by the Artillery Section of the Military Study Committee as practically unfeasible, but it nonetheless merits attention as the first scientific Russian attempt to apply the principle of jet propulsion to a solution of the problems of aeronautics.

The same principle was the basis of N.M. Sokovnin's aircraft design. Sokovnin (1811—1894), while convinced that "an aircraft must fly by some such principle as that of rocket flight,"[6] suggested using compressed air, rather than gunpowder gases, as the propulsive force.

Konstantinov, who also took an interest in possible aeronautical applications of rockets, wrote in 1856, "A rocket is a device including within itself a propulsive force, which not only propels it through the air, but also makes it capable of raising a certain weight with it, as a result of which it may at first glance appear an admirable means for the propulsion of aerostats; but closer examination shows the opposite to be true, and rockets to be less suitable for such a purpose than manpower."[7]

Konstantinov was brought to this conclusion by his experiments with a ballistic pendulum. After observing that "the results given by this instrument constitute a thorough basis for evaluation of the relative applicability of rockets and manpower to the propulsion of aerostats,"[8] he adduced the following figures: "A 4" rocket, which weighs, without tail or projectile, about 1 pud (36 lb), and whose range, under certain conditions, reaches 4 versts [4665 yd], incorporates a propulsive force of 52.92 pud-feet [1905 ft-lb], developed over a period of 2.7 seconds... Four rockets will then offer a work potential of 211.68 pud-feet [7620 ft-lb], developed over a period of 10.8 seconds, assuming the rockets are ignited consecutively. The well-known formulas determining the mechanical work which can be done by a man show that this amount of work can be done by one man in 146 seconds."[9]

On the basis of the foregoing Konstantinov wrote: "This shows that, by comparison with rockets, man is a far more efficient machine for the protracted translation over a considerable distance of large masses which must also bear the forces moving them. Human force is therefore more efficient than rockets for the propulsion of aerostats. On the other hand it has been shown impossible for the flier borne aloft by an aerostat to furnish its propulsive force, and rockets coupled to the gondola or aerostat are therefore that much more inapplicable for this purpose."[10]

In spite of Konstantinov's conclusion, efforts to solve the problems of aeronautics by means of reaction engines continued. In 1870 Treteskii revised his scheme for control of aerostats by means of such engines. As before, he proposed using the reaction of gases formed by the combustion of powder as propulsive force. Treteskii's design was considered by a Special Commission expressly formed for the purpose, but this time, too, he was refused support.[11]

The heavier-than-air jet aircraft design of N. I. Kibal'chich (1853—1881), one of the most active members of the Russian Revolutionary movement, is of great interest.

Kibal'chich, a member of "Narodnaya Volya," was executed in 1881 for an attempt on the life of Alexander II, and he drew up his aircraft design while in prison. As a result he had no time to give details of the project or work out its mathematical foundations, and was forced to limit himself to mere exposition of the idea. After his execution Kibal'chich's design was preserved in the Police Department Archives, and it was published only after the 1917 revolution.[12]

One of the most important questions confronting those working on the construction of aircraft was the choice of the most suitable energy source. After an analysis of known attempts to solve the problems of aeronautics by means of steam engines, electromotors, or the sheer physical effort of the aviators themselves, Kibal'chich concluded that all of these efforts were doomed to failure, and that the best energy source was to be found in slowly burning explosive substances.

"In fact," he wrote, "during the combustion of explosive substances a large quantity of gases which possess enormous energy at the moment of their formation is formed more or less rapidly. I do not recall exactly the amount of work, in kilogram-meters, done by the combustion of one pound of gun-powder, but unless I am mistaken, a single pound of gunpowder, exploded in the earth, will throw out a clod weighing 40 puds [1440 lb]. In short, there are no other natural substances capable of developing as great an amount of energy in a short time interval as explosives."[13]

The choice of this source of energy was by no means casual, but arose from Kibal'chich's several years as head of the Laboratory of the Executive Committee of the "Narodnaya Volya" party. As part of his preparation for revolution, Kibal'chich studied the properties of explosives with feverish energy, reading an enormous number of books on the subject in Russian, German, English, and French.

"But how," he continued, "can the energy of the gases formed in the combustion of the explosives be continuously utilized? This is possible only if the enormous energy released is not formed all at once, but over a more or less protracted time interval.

"If we take a pound of granular powder, which takes fire momentarily after ignition, and compress it under great pressure into a cylinder, then ignite one end of the cylinder, we find that the entire cylinder does not flame immediately, but that the burning spreads quite slowly from one end of it to the other, with a definite speed. The rate of spread of combustion in compressed powder has been determined from numerous experiments and is 0.4"/sec.

"The design of military rockets is based upon this property of compressed powder. The essence of this design is as follows. A cylinder of compressed

gunpowder, with an axial ignition channel drilled through it, is tightly inserted into a tin cylinder, closed at one end and open at the other. The combustion of the powder begins on the surface of the channel and spreads outward, over a certain period of time, to the external surface of the powder cylinder. The gases formed by combustion of the powder then exert pressure on all sides, but the lateral pressures respectively balance one another. The pressure on the tin shell enclosing the powder, however, which is not balanced by an opposite pressure (since on that side the gases have an unimpeded exit), pushes the rocket forward in the direction in which it was placed on the stand prior to ignition. In flight the rocket follows a parabolic trajectory like that of cannon balls shot from a gun.

"Let us now suppose that we have a sheet iron cylinder of known dimensions, closed hermetically on all sides, and having only one opening of known size in its lower end. Let a cylinder of compressed powder be placed along the axis of this cylinder, and let it be ignited at one of its ends.[14] When combustion takes place the gases liberated will exert pressure against the entire internal surface of the metal cylinder, but the respective lateral pressures will balance each other, and only the pressure against the closed end of the cylinder will not be balanced by the opposite pressure, because on that end the gases have an unimpeded exit through the opening in the bottom. If the cylinder is placed with its closed end upwards, at a known gas pressure, which depends partly on the internal volume of the cylinder and partly on the thickness of the cylinder of compressed powder, the cylinder will rise.

"I do not have at hand figures which would allow even an approximate determination of how much compressed powder must be burned in a unit of time, for a cylinder of given size and gravity, in order for the gases liberated to exert on the bottom of the cylinder a pressure balancing the cylinder's gravity. I think, however, that in practice this effect is certainly attainable, and rockets provide actual confirmation of this. Rockets are now being built which can bear upwards explosive projectiles weighing as much as 5 pud [180 lb]. It is true that the example of rockets is not entirely appropriate here, because rockets have an enormous velocity unthinkable for an aeronautic craft, but this high velocity is due to the very large quantity of compressed powder used in rockets, which provides a correspondingly great surface of combustion. If a much lower vertical flight velocity were required, the amount of powder required to be burned per unit of time would be very much smaller."[15]

In addition, Kibal'chich gave a description of his flying machine (Figure 21a), which was to be propelled by a reaction gunpowder engine *A*, placed vertically, and connected by the rods *NN* to the platform *P*, on which the aviators were accommodated.

The engine *A* was a sheet iron cylinder hermetically sealed on all sides, with an exhaust orifice *C* in its lower end. Small cylinders of compressed gunpowder *K* were to be fed into the cylinder's combustion chamber, and the gas formed by their combustion was the working medium of the engine. Kibal'chich proposed a special automatic control, operated by a clock mechanism, for ignition and continuous displacement of fuel into the chamber. He did not describe the design of this control, but remarked that "all this can easily be done by modern engineering techniques."

For fuel Kibal'chich suggested slowly burning powder compressed into cylindrical charges, but he also observed that there are many other slowly burning explosive substances, also containing nitrates, sulfur, and carbon, though in different proportion, or with admixtures of other substances, and that one of these other substances might turn out to be more efficient than gunpowder.

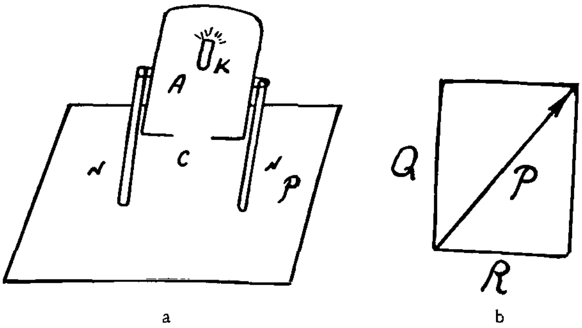


FIGURE 21. Schematic diagram of N.I. Kibal'chich's flying machine.

The ascent and descent of the machine were to be accomplished by changes in the volume of the powder cylinders fed into the combustion chamber. This variation in the amount of fuel entering the chamber made it possible to vary the lifting force as well. Horizontal motion in a given direction would be achieved either by inclination and conical rotation of the engine cylinder (which would give rise to a horizontal component of the resultant of the reactive forces, Figure 21b), or by a second engine, like the first, but placed perpendicular to it and rotating in the horizontal plane. Kibal'chich himself gave his preference to the second method, which he thought would give the aircraft more flight stability.

The fundamental difference between Kibal'chich's reaction aircraft scheme and all others previously put forward was that his "aeronautic machine" did not require the atmosphere as a supporting medium and could theoretically move also in airless space.

From a modern point of view Kibal'chich's design unquestionably suffers from many deficiencies and even from some fundamentally unsound solutions. Indeed, detailed analysis shows that the aircraft, as it is described by Kibal'chich, could not even have been built.

However, one cannot fail to admire the courage of the man who developed this design, remarkable for its day, in the death chamber, only a few days before his execution, and one must acknowledge the talent of the inventor who foresaw such technical problems as assurance of flight stability, use of multi-chamber machines, regulated combustion, jacketing of gunpowder, etc. N.I. Kibal'chich is therefore rightly regarded as one of the pioneers of rocketry.

The efforts of inventors working in the field of jet flight were certainly hindered by the fact that the representatives of Russia's scientific and technical institutes had a negative attitude to the very idea of applying a

reaction prineiple to the problem of manned flight. In 1883, for example, the Chief Engineering Board expressed itself as follows:

"With regard to the suppositions, most recently voiced, that free flight can be communicated to bodies by the continuous explosion of various explosive substances, it may be said that all explosive substances possess more crushing than projectile force, and if even black powder, which has the greatest projectile force and relatively slight crushing force, requires modification to reduce the latter if it is to be usable in rockets, it is the more unlikely that explosive substances can find application to aerial flight, whether operating directly by the reaction of their pressure upon explosion, as is the case, for example, in rockets, or in machines, for the purpose of propelling them; for any explosive, especially if it contains nitroglycerine, will sooner shatter the enclosure within which the explosion occurs than communicate to it, or to its movable wall, some gradual motion."[16]

Research on jet flight in Russia continued notwithstanding. In the middle eighties the engineers A. V. Eval'd, in St. Petersburg, and F. Geshvend, in Kiev, were working on designs for reaction aircraft. In 1886 Eval'd conducted a number of experiments with a jet airplane model.[17] As engine he used solid propellant rockets placed in a special sheet metal groove. After a series of unsuccessful attempts he finally succeeded in obtaining some positive results, but due to lack of funds could not continue his experiments.

Geshvend's 1887 design for a reaction aircraft (steam-plane) is extraordinarily interesting, but is given no detailed consideration in the present work because its energy source was a jet of steam, rather than gunpowder gases.

The above-mentioned names exhaust the list of those working on the possibility of applying the reaction of the gases formed from the combustion of densely compressed gunpowder propellants for the purposes of aviation and aeronautics, down almost to the present day. The rough notes of S. S. Nezhdanovskii, which show that this talented scientist and inventor was studying the problem of realizing flight by means of jet engines as early as the 1880's, were found, however, in the 1950's.[18]

Nezhdanovskii first thought about the possibility of building a jet aircraft in July 1880. His diary bears the entry: "A flying machine is possible with the use of an explosive substance; the products of its combustion to be ejected through something like an injector."[19]

At the end of 1880 Nezhdanovskii made several calculations relating to a rocket aircraft propelled by the reaction of gunpowder gases. Here they are presented as in his notebook:[20]

P	— pressure of gunpowder gases	200 atm
V	— their exhaust velocity ($V = 612\sqrt{\log P}$)	928 m/sec
G	— weight of the rocket charge	65 kg
p	— density of the gunpowder gases at a pressure of 200 atm	0.1
W	— volume of 4 pud [144 lb] of gunpowder gases at 200 atm pressure and density 0.1	655 dm^3
τ	— work inherent in 4 pud gunpowder at 200 atm pressure $\left(\tau = \frac{mV^2}{2}\right)$	$285 \cdot 10^4$ kg-m
S	— duration of flight	300 sec

Making calculations for two versions of the engine (with gas pressures, respectively, of 150 and 200 atm), Nezhdanovskii concluded: "I think it entirely possible to build a flying machine which can carry a man through the air for at least 5 minutes. A funnel emitting air with the most efficient velocity will conserve fuel and increase flight duration."[21]

In the future Nezhdanovskii continued to study the problems of jet flight, but unlike most of the inventors working in this field, almost entirely neglected aircraft design, concentrating instead on the construction of the jet engine and the best fuel for it.

In his search for the most efficient type of engine, Nezhdanovskii produced a number of original ideas. In particular, in 1882 he proposed to build a jet engine "on the principle of 2- or 3-barreled magazine or machine guns, for the additional purpose of making it possible to control the force and flight duration."[22]

Another idea of approximately the same period was to use special nozzles, so that when the stream of gunpowder gases passed through them, it would draw after it atmospheric air, thus, according to Nezhdanovskii, greatly increasing the jet effect.[23]

Nezhdanovskii devoted a great deal of attention to the choice of a working medium, considering as energy source nitroglycerine, compressed air, steam, carbon dioxide, and various explosive mixtures. Of solid fuels Nezhdanovskii considered two types — powder-cotton and conventional black (smoky) powder, calculating the exhaust velocity of the gases from a pipe filled with gunpowder pulp, the mass of fuel used per second, and the work obtained. He concluded that the cotton powder incorporated three times as much energy as the smoky black powder.[24]

After several years of work, Nezhdanovskii at the end of the 1880's again considered the use of rockets for flight. In 1889 he noted in his diary: "Can one not build a flying inclined plane with a rocket to impart horizontal velocity to it? Which is more efficient, a simple rocket or a rocket with inclined plane? Is not the simplest form of flying machine simply a rocket with an inclined plane?"[25]

It is apparent that the authors of most of the above-mentioned schemes limited themselves to exposition of the working principle of the engine, without presenting structural details or a precise calculation of the amount of energy required to realize jet flight. They cannot therefore be regarded as engineering projects, but were rather demands for inventions. Not one of these proposed aircraft schemes reached the stage of construction during the 19th century.

NOTES

1 Here and subsequently the information given on aircraft designs developed outside Russia is based on non-Russian sources.

2 More details of the reaction aircraft designs proposed in Russia are given in a lecture delivered by the author in April 1961 at a session of the Aviation Section of the Soviet National Union of Historians of Natural Science and Engineering. This lecture is now being prepared for publication.

3 Memorandum of Captain Treteskii, Field-Engineers' Corps, to the Commander-in-Chief of the Independent Caucasus Corps, 13 March 1849. TsGVIA, store 1 (1), entry 1, file 17464, sheet 31.

4 Treteskii. O sposobakh upravlyat' aerostatami. Tiflis, 1849 (Manuscript). TsGVIA, store 1 (1), entry 1, file 17464, sheets 35—140.

5 Ibid., sheets 59 obverse—60.

6 Sokovnin, N. Vozdushnyi korabl' (Aircraft).— p. 35. Sankt Peterburg, 1866.

7 Morskoi sbornik, No. 8, part III, p. 99, 1856.

8 Ibid.

9 Ibid., pp. 99—100.

10 Ibid., p. 101.

11 Treteskii's project and the conclusions of the Special Commission have not yet come to light. Only Treteskii's reactions to the Commission's observations have been preserved. See TsGVIA, store 802, entry 3, file 79, sheets 336—338.

12 Kibal'chich, N. I. Proekt vozdukhoplavatel'nogo pribora (Design for an Aeronautical Craft).— Byloe, Nos. 10—11, pp. 115—121, 1918. Kibal'chich's plan is presently kept in the Central Government Archive of the October Revolution.— TsGAOR, D. P. section III, 1881, file 79, part I supp., sheets 1—5.

13 TsGAOR, D. P. store, section III, 1881, file 79, part I supp., sheet 2.

14 I am not certain if maintenance of the required slowness and regularity of combustion requires that the compressed powder be enclosed in a tight-fitting jacket; but even if it is necessary, it would not obstruct the use of compressed powder for the experiment (Kibal'chich's note).

15 TsGAOR, D. P. store, section III, 1861, file 79, part I supp., sheets 2 obverse—3 obverse.

16 Report of the Chief Engineering Board No. 4663, 14 April, 1883.— TsGVIA, store 401, 1883, entry 4/928, file 34, sheets 10 obverse—11 obverse.

17 Eval'd, A. Letatel'nye mashiny. Opyty i nablyudeniya (Flying Machines. Experiments and Observations), pp. 36—38. Sankt-Peterburg, 1897.

18 Designs and calculations related to jet aircraft were kept in Nezhdanovskii's daybooks, which are now preserved in N. E. Zhukovskii's Scientific Memorial Museum in Moscow. The first reports on Nezhdanovskii's research in the area of jet propulsion were given by A. I. Yakovlev, of the Moscow Aviation Institute, at a conference organized by the Department of the History of Aeronautical Engineering of MAI (9 January 1957), and at a meeting of the Aviation Section of the Soviet National Union of Historians of Natural Science and Engineering (2 March 1959).

[19] Scientific Archive of N. E. Zhukovskii's Scientific Memorial Museum, No. 1079, sheet 66.

[20] Ibid., sheet 82.

[21] Ibid., sheets 81—82.

[22] Scientific Archive of Zhukovskii's Museum, No. 290/1, p. 131.

[23] However, this idea was first expressed in print by Geshvend in 1887 in his paper "General Basis for the Construction of an Aeronautic Steamship (Steam-Plane)" (Obshchee osnovanie ustroistva vozdukhoplavatel'nogo parokhoda (parolet)), where he described a jet engine with similar nozzles. Subsequently these nozzles figured in many designs and were known in scientific literature for a long time as "Melo Nozzles."

[24] Scientific Archive of Zhukovskii's Museum, No. 2990/2, p. 38.

[25] Ibid., p. 41.

Chapter VI

SOLID PROPELLANT ROCKETS IN RUSSIA AT THE TURN OF THE 20TH CENTURY

ROCKET FLARES AT THE BEGINNING OF THE 20TH CENTURY ROCKET PRODUCTION AT THE NIKOLAEV PLANT

In the development of solid propellant rockets the turn of the 20th century was the period of least apparent progress. Although these were the years in which K. E. Tsiolkovskii and I. V. Meshcherskii were laying the foundations of the mechanics of bodies of variable mass and working out the fundamental formulas of rocket motion, their work still seemed irrelevant to those seeking to improve solid propellant rockets, and consequently had no real influence on their development.

By the end of the 19th century military rockets were greatly inferior to rifled artillery in all respects, and were no longer in use by any of the world's armies. It is true that a few inventors (Andreev, Unge et al.) attempted to improve military rockets and revive them as a sort of ordnance, but they obtained no practical results and until the end of the First World War none of the work in this area emerged from the experimental stage.

A number of countries, however, were using solid propellant rockets for illumination and signalling at the turn of the 20th century. Efforts were even made to use rockets to affect natural phenomena (hail-dispersion rockets) and to carry cameras (photo-rockets).

In Russia, during these years, firework and signal rockets, as well as rescue rockets, though in very small numbers, continued to be produced, but the output of the Nikolaev Rocket Plant consisted primarily of rocket flares, the demand for which increased steadily. From 1891 onward the annual output of flares was 8000 to 9000. Table 16, compiled from the reports of the Chief Artillery Administration,[1] gives figures on rocket production at the end of the 19th century.

As a result of the considerable increase in rocket production at the Nikolaev Rocket Plant, military demands for rocket flares were fully satisfied by the end of 1898, and thereafter production was envisaged only in quantities sufficient to cover the annual expenses for experiments, research, and other routine artillery requirements. As a result, from 1899 until the closing of the Nikolaev Plant, excepting the period of the Russo-Japanese War (1904—1905), its annual production of rocket flares did not exceed 4000.

At this period attempts to improve signal rockets were also being made in Russia. In 1902 Lieutenant-Colonel Ivanov, Commander of one of the

batteries of the 21st Army Corps, proposed replacing the rocket tail by three bars arranged like the faces of a right trihedron with the rocket at its vertex.[2]

This means of rocket stabilization possessed a number of tactical advantages. Furthermore, experiments showed that rockets equipped with Ivanov's three bars, even in high, gusty winds, suffered almost no deviation from the direction of launching and rose more rapidly and higher than the same rockets fitted with conventional long wooden tails.

TABLE 16. Production of 3" rocket flares at the Nikolaev Rocket Plant (1890's)

Year	Manufactured	Used	Number remaining at end of year
1889	5000	3431	29,270
1890	5000	4121	30,149
1891	8000	4043	34,106
1892	8000	4043	38,063
1893	8000	4479	41,584
1894	9000	3916	46,668
1895	9000	3713	51,995
1896	9000	3913	57,082
1897	9000	5932	60,150
1898	9000	4667	64,483
1899	4000	4250	64,233
1900	4000	5392	62,841

After due consideration of Ivanov's proposal, the Artillery Committee commented that "although the aforementioned superiorities of rockets equipped with three bars instead of a tail commend their adoption, the Artillery Committee nonetheless considers, in view of the fact that the withdrawal of signal rockets as one of the accepted means of signalling is now under discussion, that this proposed alteration in their design be deferred until it is known whether or not they are to be retired."[3]

The idea of discontinuing the use of rockets for signalling arose from their low quality, which resulted from the fact that they were often made in primitive laboratories without adequate control over the observance of all requirements.

In an effort to improve the quality of signal rockets, the Artillery Committee found it necessary to concentrate their production in the Nikolaev Rocket Plant, with the strictest adherence to the accepted design sketches and descriptions.[4]

At the beginning of the 20th century Russian signal rockets consisted of a thick cylindrical paper casing, force-filled with propellant, in the middle of which was an axial conical channel, covered above with a blind layer of the same propellant. Above this layer the casing was filled with powder used for slag. Attached to the lower end of the casing was a thin sheet metal pipe to the outside of which was soldered a right-angled socket of sheet metal into which the upper end of the rocket tail fitted.

For launching the rocket was suspended vertically with the tail end down. Ignition was by a firing squib.

In calm weather, free of atmospheric disturbances, the rocket rose for approximately 5 seconds to an altitude of up to 200 sagenes [467 yd], leaving behind it a long stream of sparks — a "ribbon" visible for a considerable distance in the darkness. After combustion of the blind propellant, the powder used as slag took fire, and the rocket burst.

The principle data on Russian one-pound signal rockets, 1904 model, are given below:[5]

External diameter of casing	1.75"
Internal diameter of casing	1.15"
Length of casing	15.58"
Length of ignition channel	8.66"
Length of blind propellant	1.95"
Length of tail	5'
Weight of rocket with tail	2.25 pounds

The measures taken to regulate production of signal rockets only succeeded in delaying somewhat their discontinuation by the Army. Their quality continued to be low, as before, and in 1908 they were crossed off the inventories of artillery batteries and storehouses.[6]

Despite the Artillery Committee's decision to concentrate the production of signal rockets at the Nikolaev Rocket Plant from 1904 onward, rocket flares continued to constitute the major part of the plant's production. In 1904 a new "Collection of Data on Three-Inch Luminous Rockets" (Sbornik svedenii o trekhdyuimovykh svetyashchikh raketakh), incorporating all the changes made in the design of rocket flares, was published.[7]

The Russo-Japanese War of 1904—1905 greatly affected the subsequent development of rocket flares.

All the known means for illuminating a given area were tested in conditions of war, and the performance of rocket flares was on the whole found satisfactory. The reports on the progress of the war and dispatches sent in by the commanders of the various units contained such comments as: "During the siege of Port Arthur in 1904 standard model luminous rockets found the widest and most helpful application"; "at the request of the sailors, rockets were even distributed to the patrol-vessels, where they were of service"; "the advantages of rockets are even more apparent when one considers their application on land during the second part of the war."[8]

Table 17, which gives figures for the total numbers of rockets to be found in forts and siege trains between 1900 and 1915, shows clearly the distribution of rocket flares among the various military regions of Russia.[9]

It is apparent that rocket flares were widely used in Russia, and constituted an integral part of the Russian army's illuminating equipment. During the period 1900—1915 the supply of flares increased greatly in practically all of Russia's military regions (excepting Kiev and Odessa). This was most evident in the Amur region, where the number of rockets increased by a factor of more than four — from about 3000 in 1900—1901 to between 12,000 and 14,000 in the years 1906—1914. The greatest number of flares (as high as 31,000) was found in the Warsaw region, which contained such strong fortresses as Warsaw, Novogeorgievsk, Brest Litovsk, and Ivangorod [now Deblin].

TABLE 17. Numbers of rocket flares in the military regions of Russia

	1900	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915
Petersburg region . .	—	3 754	–	3 320	3 470	4 471	5 071	4 886	5 793	5 504	5 246	1 932	5 233	5 507	5 047	—
Vilno region . . .	6 122	6 864	6 786	8 665	9 329	10 314	11 279	11 072	11 534	5 809	5 212	4 712	8 787	10 511	11 283	—
Warsaw region . . .	25 183	23 969	22 555	22 274	22 140	14 817	17 592	–	28 512	29 324	28 684	—	29 060	28 083	31 137	4 711
Kiev region . . .	1 794	1 634	1 619	1 539	1 609	1 659	1 624	1 571	1 080	1 000	920	—	840	840	478	—
Odessa region . . .	7 505	8 462	8 403	8 209	7 917	8 288	8 371	8 029	7 689	7 500	7 013	10 581	8 079	4 939	4 396	5 122
Caucasus region . .	6 711	8 109	7 827	7 216	6 824	7 090	8 998	8 830	8 870	8 777	8 927	—	8 782	7 872	7 657	7 827
Turkestan region . .	1 280	1 350	1 750	1 670	1 309	8 120	2 100	2 000	1 840	1 970	2 010	2 070	2 232	2 118	1 998	2 003
Amur region . . .	3 064	3 232	6 131	6 421	6 421	8 206	12 599	13 129	—	14 276	14 878	13 987	14 378	13 803	12 958	
Kvantun district government	2 858	2 838	3 078	2 998	—	—	—	—	—	—	—	—	—	—	—	—
Total	54 517	60 212	58 149	62 312	59 019	56 965	67 634	49 517	65 318	74 160	72 890	33 282	77 391	73 673	74 954	19 663

Military actions, however, revealed the deficiencies as well as the advantages of rocket flares. Primary among the former were low altitude and short range. The 3" flares with wooden tails used by the army had a maximum altitude of only about 1 km, and as Major-General Pomortsev remarked in one of his lecture notes, served "more to illuminate the marksman himself than his target."[10]

The primary problem confronting the inventors and designers seeking to improve rocket flares was therefore to increase their range and the radius of the illuminated surface. Those working to improve rocket flares during these years included Pomortsev, Sazonov, Ennatskii, et al. Their research is discussed in the following sections.

EXPERIMENTAL ROCKET RESEARCH AT THE BEGINNING OF THE 20TH CENTURY

For a long time a point of view widely encountered in Soviet works on the history of science was that after the discontinuation of military rockets in the 1880's, research on solid propellant rockets was actually abandoned, to be resumed only in the years immediately preceding the First World War.

This point of view has also been reflected in many popular scientific works on the history of rocketry in Russia[11] and until very recently has not even been subjected to doubt.

But the detailed study of the archives made by Soviet researchers in recent years has made it clear that the closing years of the 19th century, and more particularly, the first years of the 20th, despite the retirement of military rockets, saw intensive work on the perfection of solid propellant rockets.[12] This was to be explained both by the widespread use of rocket flares and by the zeal of individual inventors who desired to build military rockets able to compete with other types of armament.

An effort to create some such form of armament through improvement of existing solid propellant designs was being made at the end of the eighties, about three years after the Artillery Committee's decision to discontinue use of military rockets and terminate their production. In 1889 Junior Artillery Captain Andreev of the Kars-Alexandropol Fortress submitted a memorandum with a description of his design for a military rocket with tubular tail[13] (Figure 22), intended for use in all cases when the use of artillery pieces presented difficulty.

After analyzing the reasons for the retirement of military rockets, Andreev concluded that their chief drawbacks were inadequate accuracy and comparatively short range. In his memorandum he noted that the first of these deficiencies resulted from imperfect production techniques, and in particular, from the divergence, inevitable in mass production, of such parameters as the weight and volume of rocket tails, cross-sectional area of the gas exhaust orifices, distance of the axes of these orifices from the rocket axis, angles of inclination of these axes to the rocket axis, etc.

These divergences, which were aggravated still more by the uneven combustion of the propellant, led to a substantial difference in the magnitude, direction, and distribution of the points of application of the forces acting on rockets of the same type, and were a cause of the considerable deviation of military rockets of earlier design.

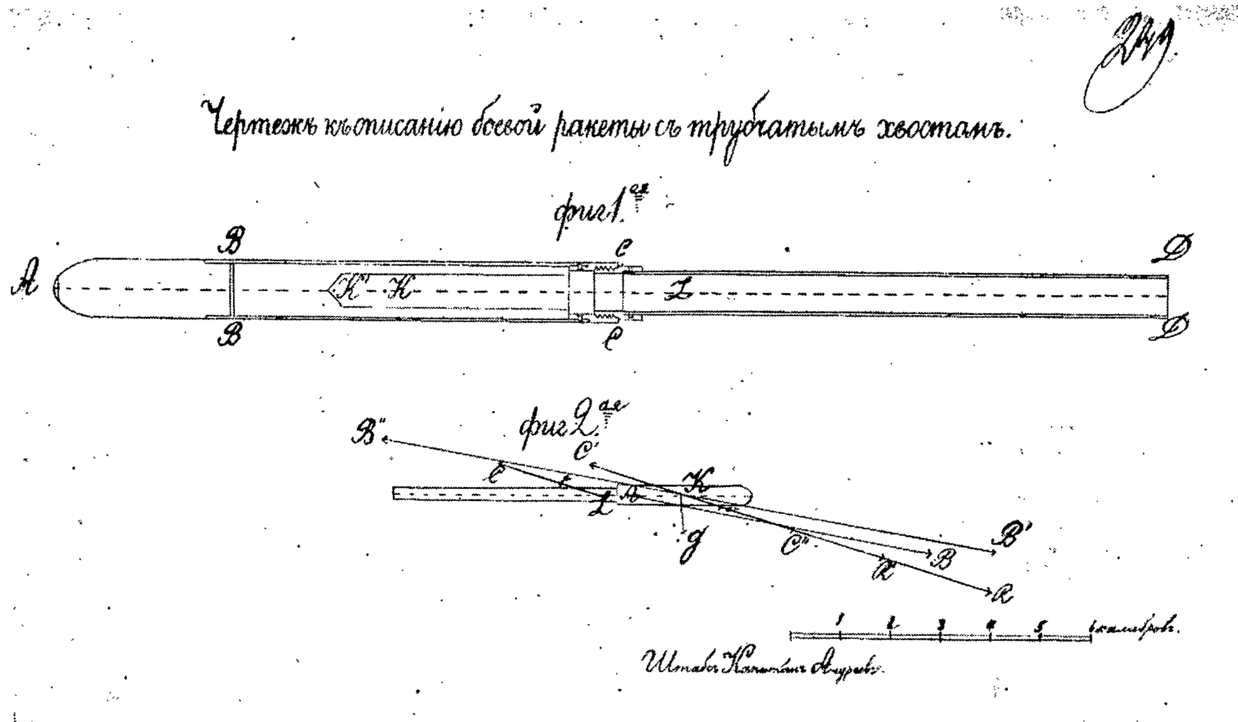


FIGURE 22. Andreev's design for a military rocket with tubular tail.

In his memorandum Andreev attempted to give a schematic representation of the forces acting on a rocket in flight (Figure 22, sketch 2). "At any given moment," he wrote, "let AB be the resultant of the propulsive force and force of friction, Kg, the force due to gravity, and LC, the air resistance. Their transposition to the point K produces one force KR' and the couple $LC — KC''$, which can be resolved into two force couples: one, lying with the axis of the rocket in the vertical plane, and another, whose plane is perpendicular to the vertical and also passes through the rocket axis. The first couple will tend to make the rocket axis coincide with the tangent to the trajectory, while the second will make the rocket deviate from the vertical plane (plane of shot), while the center of gravity of the rocket will be shifted in the same direction away from the plane of the shot by the force KR'. Since the magnitude and direction of the force KR' and of the couple $LC—KC''$ for rockets are different because the magnitude, direction, and point of application of their components are different, rockets will behave extremely differently one from another in flight."[14]

The second deficiency of military rockets — their comparatively short range — was, in Andreev's opinion, purely the result of imperfect design in the old type of rockets, and arose specifically from the small total area of the gas exhaust orifices and insufficiently long casings. Andreev thought range to be dependent on the power of the propellant and the length of the casing, and insisted on increasing these as much as possible, with the reservation that existing rocket designs did not permit a propellant force (and therefore a gas pressure) exceeding a certain value dependent on the strength of the casing.

These considerations led Andreev to the conclusion that any improvement of military rockets depended, in the first place, on elimination of the causes of the above-mentioned shortcomings.

"Thus," ran his memorandum, "to increase the accuracy and range of a rocket its design must be so modified as 1) to reduce the influence of production errors, 2) make possible the adoption of a more powerful propellant for filling, without having to strengthen the casing walls, and 3) increase the length of the casing, without unnecessarily increasing the weight of the rocket in so doing."[15]

Seeking to satisfy these requirements, Andreev proposed replacing the solid wooden tail by a hollow tube of sheet steel whose axis would be an extension of the axis of the casing, claiming that by the methods then known for the production of iron tubes and casings the tail could thus be given very nearly cylindrical form.

The tubular tail was to be screwed onto the rocket casing in place of a sleeve designed to keep out dampness immediately before launching. The internal diameter of the tail depended on the power of the propellant, and its length, on the moment of the force couple which tended to make the rocket deviate from its proper direction.

Andreev summarized the superior features of the tubular tail, as opposed to the solid one, as follows:

"1) The tubular tail can make the rocket fly truer because its errors will be smaller than those of a central tail;

"2) it makes it possible to use a more powerful propellant since the gas exhaust area can be made equal to the area of the casing and

"3) it increases the range of the rocket independently of the power of the propellant."[16]

Andreev's military rocket with tubular tail (see Figure 22, sketch 1) consisted of a sheet iron casing *BC*, to which was attached a tail *CD*, in the form of a hollow tube, also of sheet iron. The forward part of the rocket carried an explosive head *AB* or a quantity of shrapnel with the tube *A*.

Andreev expected his innovations to increase the range of 2" rockets to as much as 1000 or 1200 ft/sec, as well as to improve their accuracy substantially to the point of making it comparable with that of the mountain ordnance of 1867.

Andreev also pointed out that the same changes could be made in rocket flares, increasing the radius illuminated to 800 sagenes [1867 yd], or a distance equal to that at which the objects illuminated could be examined.

The design received almost no further development, however. In the concluding part of his explanatory memorandum, Andreev wrote: "This short description gives only the ideas and the advantages which will derive from their adoption. It gives no information about the projectile or the relative position of the centers of gravity and the figure, because the manuals used do not give the information required for this purpose."[17] Furthermore, Andreev was not sufficiently clear on the source of the reactive force. For example, he took the view that the "rocket moves only because the gases liberated seek to eject from the casing the previously liberated and lost part of the kinetic energy, as a result of which the greater this mass of gases, against which the newly liberated gases act, the greater will be their efficiency, and in consequence, the range of the rocket."[18]

At the same time he correctly noted that "the efficiency of the gases will be a maximum when the length of the casing is such that the pressure of the outflowing gases is equal to one atmosphere, though this would result in an exceedingly long casing."[19]

In November 1891 Andreev's design was discussed at a session of the Artillery Committee, with the following result: "In view of the lack of details in Junior Captain Andreev's memorandum, and taking into account the fact that military rockets are no longer in use, the Artillery Committee does not see its way clear to support further development of his idea; the more so since the Committee's opinion is that a rocket possessing a tubular iron tail of the same length as a wooden tail will be extremely heavy, and that reduction of this weight by shortening the tail will only result in diminished flight accuracy. For these reasons the Artillery Committee has decided to reject the proposal of Junior Captain Andreev."[20]

No other information as to the fate of this design has been found, and it was evidently destined simply to lie gathering dust in the files of the Artillery Committee. Nor is it known if persons later engaged in rocket research had access to these files and acquired any knowledge of Andreev's design. Whatever the case, in a number of schemes dating from the beginning of the 20th century Andreev's idea of replacing the wooden tail by a hollow metal tube is repeated in one form or another, though without any reference to his work.

Our information on the experimental solid propellant rocket research conducted in the 1890's is also very slight. It is true that the Artillery Committee files contain references to the fact that "Section V of the Committee, working on winged rockets, succeeded as early as 1892 in

replacing the wing by three boards arranged like the edges of a right trihedron,"[21] but the passage leaves it unclear whether military rockets, signal rockets, or flares are being discussed, and what results were attained. No other references to the experiments of this period have so far been discovered.

The next information on the experiments on rocket flares and military rockets conducted in Russia pertains to the beginning of the 20th century. During the years 1902—1917 the Russian engineers and inventors working on solid propellant rockets included Volovskii, Gerasimov, Demenkov, Karabchevskii, Linevich, Makhonin, Pomortsev, Sazanov, Sytenko, Ennatskii, and others. The researches of M. M. Pomortsev, N. V. Gerasimov, and I. V. Volovskii are of particular interest.

Pomortsev wished to build a special "reaction glider," propelled by a 3" rocket flare, attached to a tubular rod bound by thin steel wires to the tubular axis of the glider, and forming with it a parallelogram.[22] He intended the lift of the glider to keep the illuminating compound (or other projectile) aloft, and its aerial stability would compensate for the lack of a rocket tail. The preliminary calculations made by Pomortsev in 1902 showed that a glider with lifting surface area of 1 m^2, using standard 3" rockets, could attain a range of 3 versts [3500 yd], and that this could be greatly increased by using rockets with slower burning propellant.

At first glance Pomortsev's experiments seem like those of Eval'd (see p. 105) but their purposes were completely different. While Eval'd sought to use the propulsive force of rockets to power his aircraft, Pomortsev's primary intention was to improve the accuracy of rockets carrying explosives and illuminating compounds over great distances by the use of lifting surfaces. The first series of his experiments involved signal rockets and from the first had a more pronouncedly aerodynamic character. "The object of the rocket experiments described below," Pomortsev wrote in 1903, "was to study the motion of various types of surfaces propelled in air with considerable velocities and to test the conclusions arrived at by myself and other researchers in studying motion at relatively low velocities, in order to apply the results obtained to increasing the flight accuracy of the rockets themselves."[23]

The experiments consisted of attaching to signal rockets lifting surfaces of various shapes (Figure 23, 1—8), consisting of steel frames wound about with sheets of aluminum or some more durable material. The surfaces being studied were first tested in air without rockets, using rubber propellers, and were then attached to the rockets, either directly (Figure 23, 1—4), or to a rod from which the rocket was suspended (Figure 23, 5, 6).

The results were quite negative: no sooner was a rocket with the attached supporting surfaces fired, than the entire system, moving forward, lost its stability and began to rotate about its longitudinal or transverse axis.

A number of tests with supporting surfaces of the form described brought Pomortsev to the conclusion that "the flight of rockets cannot be made true by the use of surfaces whose direction coincides with the axis of the rocket, since the least angle between this plane and the axis gives rise to a torque couple which throws the rocket off course."[24]

The next series of experiments was conducted with tubular stabilizing surfaces, either cylindrical or slightly conical in form[25] (Figure 24, 9—12).

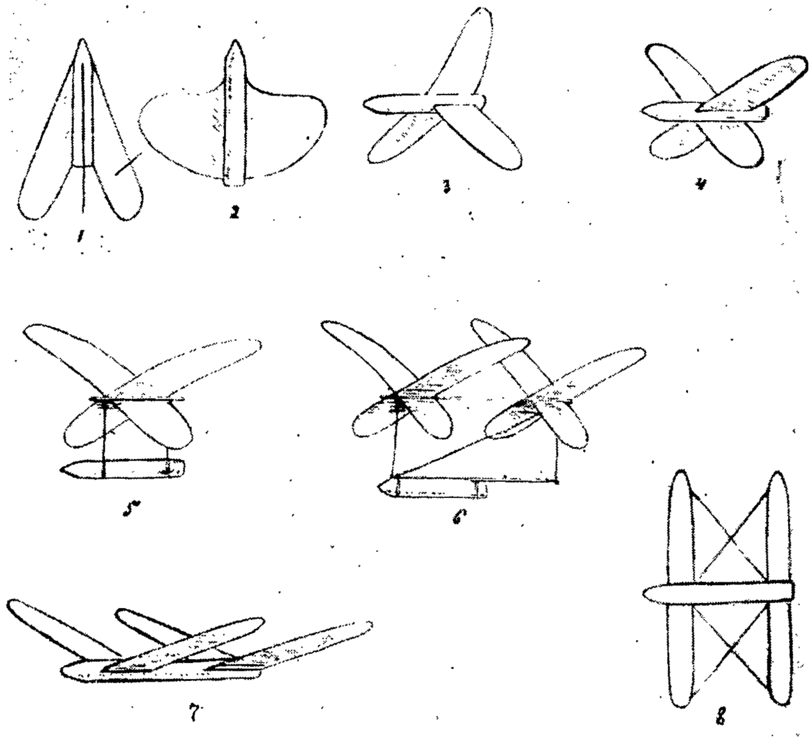


FIGURE 23. Rockets with stabilizing surfaces of M. M. Pomortsev's design.

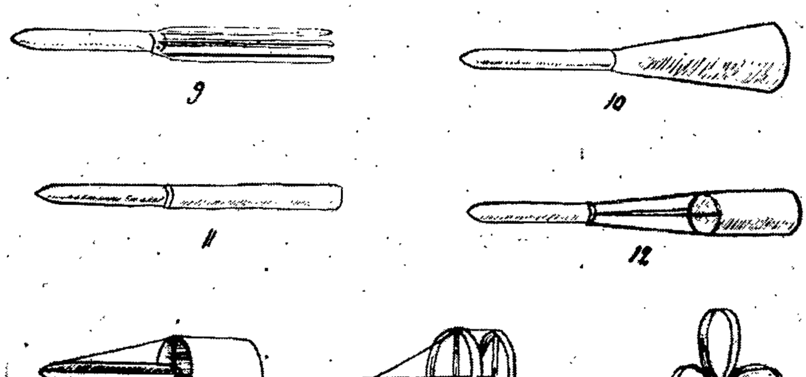


FIGURE 24. Rockets with tubular stabilizing surfaces of Pomortsev's design.

They were made of aluminum sheet or of thin steel strips, and were attached to the end of the rocket casing, like an extension of it. This clearly was essentially a variant of Andreev's idea (see pp. 115—116).

The experiments conducted with these tubular surfaces resulted in flight of satisfactory stability, but greatly reduced range, due, in Pomortsev's opinion, to reduced gas exhaust velocity because of considerable friction against the walls of the tubes.

On the basis of these results, Pomortsev greatly increased the diameter of the tube and obtained a cylinder open at both ends, which was attached to the rear end of the rocket casing and was coaxial with it (Figure 24, 13). The results exceeded all expectation. Rockets equipped with ring stabilizers of this type suffered hardly any deviations from course in flight tests, even with a relatively high side wind.

Further experiments were made with rocket flares, using the surfaces described above, with the object of determining the most favorable dimensions for all parts. The rockets tested were launched from a stand (Figure 25), to the forward end of whose housing four bars of thick T-shaped iron were securely attached.

The ring stabilizers (Figure 26) were made of thin but wide strips of steel, or of aluminum sheets mounted on steel bands. Their length and diameter varied between wide limits. As the experiments performed by Pomortsev at Kronstadt in 1903 showed, the length of the ring stabilizers was not significant, whereas their diameter greatly affected the stability of the rockets.

"An explanation for this last fact," wrote Pomortsev, "is to be sought in the fact that in rapid motion of the rings the air resistance acts, for the most part, upon a part of the ring very near to its leading edge, and consequently, beyond known limits the rear surface of the ring does not participate in the air resistance component, serving only to increase the friction of the air particles.

"When there is some lateral deviation of the rocket axis from the direction of motion, the annular surface, which also forms some angle with the motion, will immediately give rise to a couple of forces which restores the disturbed equilibrium, and the stability of the rocket becomes greater, the greater the moment of the forces thus created about the axis of the casing, i.e., the greater the diameter of the ring."[26]

The above makes it apparent that in his research Pomortsev devoted a great deal of attention to the analysis of rocket flight dynamics. In his efforts to attain flight stability, he concluded that the essential thing in stabilizing a rocket is the mutual position of the center of pressure (or, as Pomortsev termed it, the center of air resistance) and the center of gravity.

"However well a rocket is made," Pomortsev wrote in 1903, "when it is in motion it is always possible for the axis of the rocket to make some angle with the direction of motion. At small angles of inclination and high velocities the center of air resistance is certainly very close to the head of the rocket, to a large extent because of the considerable resistance to the latter. As a result the center of gravity of the rocket (located 53 cm from the forward end in a luminous rocket) will pass behind the center of air resistance, and the rocket in motion will be in a state of unstable equilibrium. The equilibrium will continue to be disturbed until the axis of the rocket makes such an angle with the direction of motion that the center of air resistance moves back relative to the center of gravity. When this happens the resulting pressure on the rear of the rocket will move the

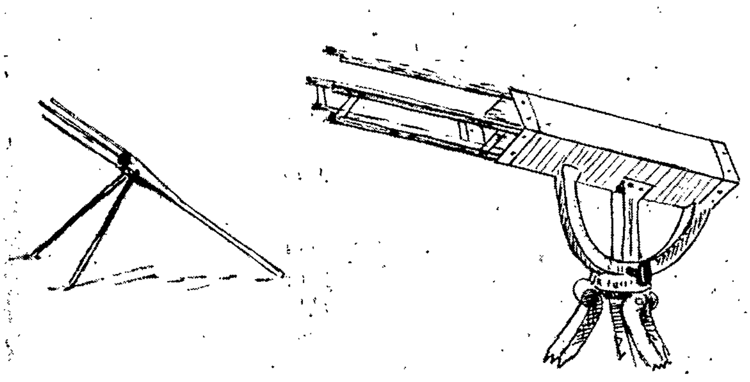


FIGURE 25. Rocket launching stand designed by Pomortsev.

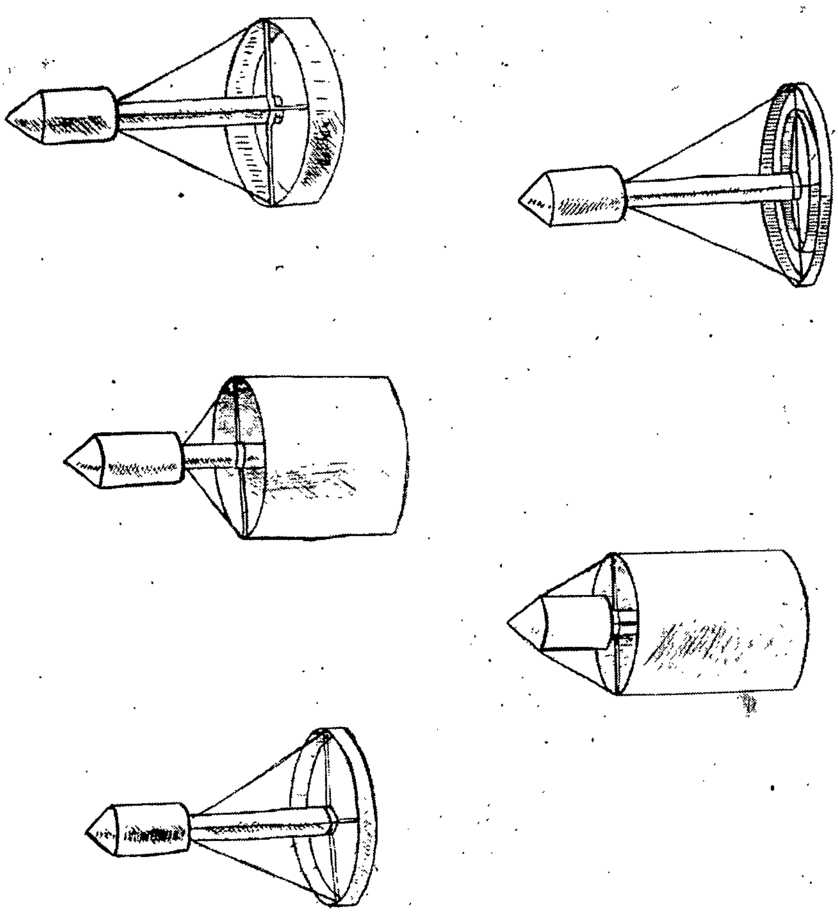


FIGURE 26. Rocket flares with ring stabilizers designed by Pomortsev.

rocket axis by inertia in the direction opposite to the preceding, etc.

"The result of all this is an oscillatory motion of the rocket, always observable in rockets with tails and reaching 10° and more in luminous rockets, which , absorbing the enormous propulsive energy of the rocket, reduces its range and increases its inaccuracy. "[27]

"From the above," Pomortsev continued, "we can conclude that the motion of modern rockets is very like that of a projectile shot from a cannon, while the restoration of a rocket's equilibrium is accomplished by an oscillatory motion about its longitudinal axis. "[28]

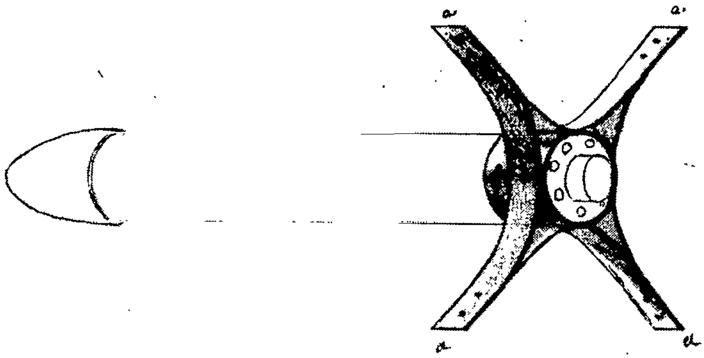


FIGURE 27. Rocket with cruciform guide.

Later on, continuing his search for improved means of rocket stabilization, Pomortsev suggested replacing rocket tails by a special vane consisting of four steel bands. A steel sleeve *A* was fitted directly onto the rear end of the rocket (Figure 27), to which were riveted four half-rings *a*, made of steel bands 1 mm thick and 50 mm wide. The tangent ends of the bands were riveted together in pairs, forming a spider.

Pomortsev designed a special stand for launching rockets with this type of stabilizer (Figure 28). Its upper end, consisting of four guide bars *B* of sheet iron, fastened at one end to the iron binding *C*, was attached to a small tripod and could be set up at any angle to the horizon. The total weight of the stand was about 16 kg, which made it easy to transport.

Pomortsev's two years of experimentation on solid propellant rockets yielded a number of positive results. In his report of April 1905 to the Artillery Committee he wrote: "I now regard my experiments on 3" rocket casings of current type, propelled by gunpowder gases, which I began two years ago with the support of the Artillery Committee, as concluded, and I present their results in this report.

"My first purpose in these experiments, which consisted of the attainment of long range, high velocity and accuracy of rockets, in order to use them for conveyance of explosive projectiles, may be regarded as achieved. Rocket casings with the stabilizers I fitted to them attain ranges of 2—3 versts [2335—3500 yd] before descent, and describe correct trajectories like those of spherical projectiles shot from mortars. "[29]

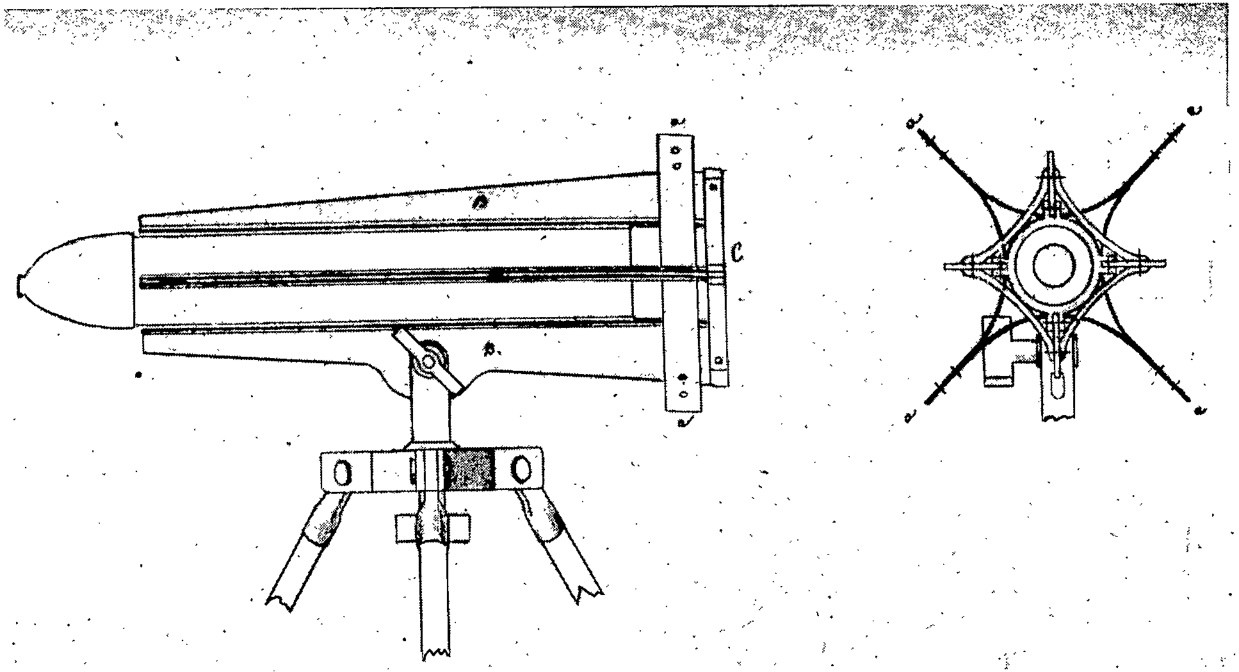


FIGURE 28. Stand for launching rockets with cruciform guides.

Later Pomortsev achieved even better results. In December 1905 he noted that standard 3" rockets, in which, however, the boxes of illuminating compound had been replaced by heavy cones, and the wooden tails by steel guides attached to the end of the casing, could attain ranges "of as much as 3—4 versts [3500—4700 yd] with considerable trueness in flight."[30]

"A like result," continued Pomortsev, "may be obtained with luminous rockets, if the diameter of the box with the luminous compound is decreased. This can be done, without decreasing the number and size of the pellets, by a corresponding increase in the length of the box. The pressure of the gases formed by combustion of the propellant must be increased as well; this condition requires an increase in the strength of the metal casing."[31]

On the basis of these data, the Artillery Committee decided to continue with the program of experiments on rocket flares outlined by Pomortsev. It was decided to order 500 steel casings from the Société Métallurgique de Montbard in Paris, in order to determine the minimum size of gas exhaust orifices which would not lead to bursting of the casings. In addition, the Nikolaev Rocket Plant was instructed to collaborate with Pomortsev on the development of a new packing for luminous charges which would entail a box no more than four inches in diameter.

Pomortsev's positive results with illuminating rockets gave the Artillery Committee a basis for returning to the idea of improved designs for military rockets. Pomortsev in fact proposed to develop two types of military rockets: incendiary (if thermite could be used in them) and high explosive rockets. The Artillery Committee rejected the idea of case-shot rockets with the comment that "the velocity of the rocket at the moment when the shell containing the bullet bursts will be too low to give the bullets adequate velocity for satisfactory performance."[32]

The proposed experiments, however, could be begun only in the second half of 1907.[33] Pomortsev, Head of the Gunpowder Workshop of the Nikolaev Rocket Plant, Lieutenant-Colonel Karabchevskii, the chief plant mechanic, the engineer Demenkov, and Captain Ennatskii, representing the Artillery Committee, participated.

The first series of experiments aimed at determination of the gas pressure in the casing in order to clarify the dependence of this pressure on the area of the exhaust orifices, the dimensions of the ignition channel, the method of propellant filling used, and other factors.

During the experiments the rockets were placed in cast iron cases of approximately the same length as the rocket itself. In the center of the case bottom was drilled a hole into which was inserted the receiver of a Richard dynamometer. The rocket being tested was fitted into forks inside the case specially arranged so that the axis of the rocket passed through the center of the receiver piston. When the rocket's forward end touched the piston, its other end with the gas exhaust orifices projected beyond the end of the case and the gases could flow out into the air unobstructed. The case was placed on the bottom of a pit dug in the ground and the recorder of the dynamometer, connected with the receiving piston by a copper tube, was located inside a building next to the pit.

In this way all the tests could be safely conducted inside the rocket plant.

The very first experiments showed that the conical parts of the seamless casings delivered from France, drawn into the form of sleeves, were not strong enough. They often failed to withstand the gas pressure, showing

TABLE 18.* Results of stand tests of rockets at the Nikolaev Plant (second half of 1907)

No.**	S_{orif} (sq in)	d_{chan} (in)	l_{chan} (in)	Q (atm)	P (kg)	t (sec)
Casings of three-inch rockets with six gas exhaust orifices						
1	2.70	0.75	15	40	100	2.0
9	2.70	0.75	15	40	193	1.5
3	1.84	0.75	15	20	200	1.0
10	1.84	0.75	15	20	200	1.25
11	1.84	0.75	15	20	200	1.5
12	1.84	0.75	15	20	180	1.5
2	1.84	0.75	15	40	140	1.0
6	1.84	0.75	15	40	143	?
7	1.84	0.75	15	40	220	1.75
8	1.84	0.75	15	40	220	1.75
21	1.84	0.75	15	40	180	1.5
22	1.84	0.75	15	40	190	1.75
23	1.84	0.75	15	40	195	1.75
26	1.84	0.75	15	40	200	? (Casing burned through)
27	1.84	0.75	15	40	200	1.0
28	1.84	0.5	15	40	180	2.25
29	1.84	0.5	15	40	110	2.5
Three-inch seamless casings with one central orifice						
16	7.0	1.0	15	40	150	1.75
17	7.0	1.0	15	40	140	1.5
13	1.48	1.0	15	40	185	1.5
30	1.48	1.0	15	40	Over 200	1.75
4	0.78	1.0	15	40	240	1.75
14	0.78	1.0	15	40	155	1.2
31	0.78	1.0	15	40	250	1.75
24	0.78	0.75	15	40	Over 250	1.33
25	0.78	0.75	15	40	" 250	1.5
18	0.78	0.5	15	40	" 270	2.0
19	0.78	0.5	17	40	" 300	2.0
20	0.78	0.5	19	40	" 300	1.5
5	0.44	1.0	15	40	Over 300	? (Casing burst)
15	0.44	1.0	15	40	" 300	1.0

* AIM Archive, Artillery Committee store, entry 39/3, file 585, sheets 50–67.

** Numbers of the tests as given in the journal of the experiments; S_{orif} is the area of the central gas exhaust orifice; d_{chan} is the diameter of the ignition channel; l_{chan} is the length of the ignition channel; Q is the pressure at which the rocket was pressed; P is the maximum dynamometer pressure; and t is the time required for combustion of the rocket propellant.

cracks and even burnout of the metal. It was therefore decided to cut off the lower parts of the casings and replace them by specially machined sleeves of the same shape, manufactured in the workshops of the Nikolaev Rocket Plant. These sleeves were fastened to the casings by the cold method of squeezing the casings at the base plate and rolling their edges onto the lip of the base plate.

Table 18 gives the results of measurements of the pressure developed by the gases in the rockets. It turned out that combustion of the blank propellant in the rockets occurred entirely without accompanying pressure. The rise and fall of the pressure, however, occurred very rapidly, so that all the curves showed more or less marked jumps at a pressure of about 100 kg on their ascending arms, while the descending arms were completely smooth.

Because of the lack of precise information as to the maximum possible pressure in the rocket casing, Pomortsev erroneously set its upper limit at 200 kg and ordered a dynamometer calibrated only to this maximum. The gas pressure in the rockets of his design with one central exhaust orifice often rose to 300 kg and more. In these cases an approximate visual estimate of the upper limit was made, and required refinement.

A notable point is the substantial divergence in maximum pressure values for rockets of the same type. In Pomortsev's opinion, this was to be explained both by deficiencies in the recording mechanism and by differences in the construction of the rockets themselves. He therefore compiled mean indices for all the figures given in the tables (Table 19).

TABLE 19. Mean indices for stand tests of 1907

S_{orif} (sq in)	d_{chan} (in)	l_{chan} (in)	Q (atm)	P (kg)	t (sec)
		Casings with central orifices			
7.0	1	15	40	145	1.75
1.48	1	15	40	195	1.75
0.78	1	15	40	215	1.5
0.78	0.75	15	40	Over 250	1.33
0.78	0.5	15–19	40	" 300	2.0
0.44	1	15	40	" 250	Burst
		Casings with 6 orifices			
2.7	0.75	15	40	145	1.75
1.84	0.75	15	20	195	1.25
1.84	0.75	15	40	185	1.5
1.84	0.4	15	40	145	2.25

Note. Letter designations as in Table 18.

By analysis of this table Pomortsev was able to ascertain a number of general laws for all rockets of the type examined. It was first noticed that a substantial change in the area of the gas exhaust orifices has no great effect on the maximum pressure and the time for which the rocket propellant burns. They were considerably more affected by the diameter

and length of the ignition channel. Pomortsev concluded, however, that in the case of the 3" rockets being tested it was dangerous to make the exhaust orifice too small (less than 0.5 in^2), since with an orifice of this cross-sectional area the pressure in the casing would rise so high as to create the danger of its bursting.

After termination of the experiments to measure the pressure developed in the casings, the second part of the tests was begun. This consisted of launching rockets with new types of stabilizers devised by Pomortsev (annular and cruciform guides, attached to a separate sleeve, and screwed onto the threaded part of the casing only immediately before launching).

To launch these rockets Pomortsev designed special stands, two of which were built in Petersburg, and a third, in the workshops of the rocket plant. Test launchings, whose results are given in Tables 20 and 21, were carried out at Nikolaev and Ochakov in September and October 1907.

These tables show that the range of the rockets equipped with annular and cruciform guides greatly exceeded that of those with a wooden tail, while the greatest range was attained by the rockets found in previous experiments to develop the maximum gas pressure, i. e., those whose *ignition channel* had the highest length/diameter ratio, and whose exhaust orifices were smallest (see Table 20, October, Nos. 12, 13, 21, 22).

When the results are considered from the point of view of flight accuracy the superiority of rockets with circular (annular) guides is evident (83% of military rockets with such guides followed the directrix, as opposed to 65% of those with cruciform guides; for rocket flares the figures are 75% and 70%, respectively).

On the basis of all these experiments Pomortsev came to the following conclusions, laid out in his report of December 1907 to the Artillery Committee:

"1) The kinetic energy or power of the rocket increases with decrease of the diameter of the ignition channel and, in particular, with increase of its length.

"Decrease of the cross-sectional area of the gas exhaust orifices has the same effect, though to a much lesser degree.

"Combustion of the blank propellant has practically no influence upon the pressure.

"2) Full combustion of the channel, which raises the pressure, is accomplished in a very short period of time, from one to two seconds, and this period is decreased with increase of the gas pressure inside the rocket.

"Increasing the compression force of the rocket propellant beyond the established limits (about 150 pud [5400 lb] per sq in) has very slight effect on the combustion time of the propellant and the gas pressure.

"3) Rockets with one central gas exhaust orifice, all other things being equal, give greater pressure and power than rockets with a series of smaller lateral orifices. The former also are much more accurate in flight than the latter.

"4) Rockets with steel guides fastened to their rear end give considerably longer range, higher velocity, and greater accuracy than rockets of the old type with wooden tails.

"5) Military rockets of the new type have a range of 5 to 7 versts [5850 to 8200 yd], but with more careful development (by means of experiments) and manufacture of their parts and improvement of the launching stand, there is good hope of increasing these distances even more without altering the diameter of the rocket itself."[34]

TABLE 20.* Tests of rockets with conical steel missiles

Month of testing	Numbers assigned in test diary	Cross-sectional area of orifice, sq in	Diameter of ignition channel, in	Length of ignition channel, in	Diameter of guides, in	Weight of rocket with missile, kg	Launching angle of stand, degrees	Range of rocket, versts	Notes
				Circular (annular) guide					
September	2	0.78	1.0	15	8.0	23	40	Over 6	Along directrix
"	11	0.78	1.0	15	9.0	22,33	35	" 6	"
"	12	0.78	1.0	15	8.5	26.5	35	" 6	"
October	11	0.78	1.0	15	8.0	28.5	40	" 3	To left of stand
"	7	0.78	1.0	15	8.0	28.33	40	Up to 4	Along directrix
September	13	0.78	1.0	15	8.0	25.33	35	Over 6	"
				Cruciform guide					
October	22	0.44	0.75	15	8.0	26.25	33	Up to 7	Along directrix
"	27	0.44	0.75	15	8.0	26.25	33	5	"
"	21	0.44	0.75	15	8.0	26.25	35	Over 6	To left of stand
"	12	0.78	1.0	17.0	8.0	28.5	37	" 7	Along directrix
"	13	0.78	1.0	17.0	8.0	26.0	35	" 7	"
"	17	0.78	1.0	15.5	8.0	25.0	35	5 — 6	"
"	18	0.78	1.0	15.5	8.0	25.75	35	Up to 5	"
September	1	0.78	1.0	15.0	8.0	22.33	40	4 — 5	"
"	8	0.78	1.0	15.0	8.75	22.0	35	4 — 5	To right of stand
"	9	0.78	1.0	15.0	8.75	22.0	35	Over 6	To left
"	10	0.78	1.0	15.0	10.5	25.0	35	" 6	To right
October	3	1.0	1.0	17.0	8.0	28.5	37	5 — 6	Along directrix
"	8	1.0	1.0	15.5	8.0	28.0	37	3 — 4	To right of stand
September	18	1.84	1.0	15.0	12.25	25.0	45	Up to 3	Along directrix
				With wooden tails					
September	14	1.84	1.0	15.0		27.0	45	2 — 3	Considerable tail wobble
"	15	1.84	1.0	15.0		26.5	45	2 — 3	ditto
"	19	1.84	1.0	15.0		?	45	?	Burst while ascending
				Failures					
October	1	1.0	1.0	17	Cruciform	28	33	—	In launching from new stand, ricochetted due to lengthening
"	2	1.0	1.0	17	"	28	37	—	
"	23	0.44	0.75	15	"	26	35	—	Missiles torn out of casings during flight
"	28	0.44	0.75	15	"	26	35	—	

* AIM Archive, Artillery Committee store, entry 39/3, file 585, sheets 50—68 obverse.

TABLE 21.* Tests of luminous rockets with elongated caps

Month of testing	Numbers assigned in test diary	Cross-sectional area of orifice, sq in	Diameter of ignition channel, in	Length of ignition channel, in	Diameter of guides, in	Weight of rocket with missile, kg	Launching angle of stand, degrees	Range of rocket, versts	Notes
				Circular (annular) guide					
October	14	0.78	1	17.0	8	36.0	48	Up to 2.5	Along directrix
September	4	0.78	1	15.0	8	34.5	45	" 3.0	To left of stand
October	4	1.0	1	17.0	8	35.0	47	" 2.0	Along directrix
"	9	1.0	1	15.0	8	35.0	48	Over 2.5	"
				Cruciform guide					
"	25	0.4	0.75	15.0	10	35.75	46	Up to 2.0	To left of stand
"	26	0.4	0.75	15.0	10	36.33	46	" 2.0	"
"	16	0.78	1.0	17.0	10	35.5	48	" 2.25	Along directrix
"	15	0.78	1.0	17.0	10	36.0	48	" 2.0	To right of stand
"	24	0.78	0.75	15.0	10	35.0	45	" 2.25	Along directrix
"	20	0.78	1.0	15.5	10	35.5	46	" 2.0	"
"	19	0.78	1.0	15.5	10	35.5	48	" 2.25	"
"	5	1.0	1	17.0	10	36.0	45	" 2	"
"	10	1.0	1	15.5	10	34.5	48	" 2	"
September	20	1.84	1	15.0	14.5	35.5	48	2–3	Along directrix
"	5	1.84	1	15.0	14.0	35.0	48	2–3	To right of stand
"	6	1.84	1	15.0	15.5	36.5	48	2–3	"
"	7	1.84	1	15.0	9.5	35.5	48	2–3	"
"	21	1.84	1	15.0	11.5	35.5	45	2–3	"
"	22	1.84	1	15.0	11.0	36.5	45	2–3	"
				With wooden tails					
"	16	1.84	1	15	—	39.0	49	?	Tail broken by excessive wobble
"	17	1.84	1	15	—	39.5	49	Up to 2	Along directrix
				Failures					
"	3	1.84	1	15	Circular	35.5	45	—	Base plate burned out, fell near launching point
October	6	1.00	1	15	Cruciform	35.5	45	—	Defective cross piece ricochetted
"	29	0.44	0.75	15	"	36.0	43	—	Annulus with cap thrown out while ascending
"	30	0.44	0.75	15	"	36.0	43	—	

* AIM Archive, Artillery Committee store, entry 39/3, file 586, sheets 50–69.

At this point experimentation on military rockets and rocket flares had to be broken off, since the Nikolaev plant's lack of heated workshops did not permit its continuation during the winter. Not wishing to lose time, however, Karabchevskii and Demenkov decided to test Pomortsev's stabilizers on signal rockets, of which there was always a good supply at hand.

At this time Russian signal rockets consisted of a paper casing to which a wooden tail was attached by means of an iron charger. The casing was 16" long and 1.75" in diameter, with a weight, when filled, of 1 lb 40 zolotniki [1.42 lb].[35]

In January 1908 comparative tests of signal rockets with various types of stabilizers were held on the rocket plant's testing ground. Conventional wooden tails 5 ft in length, shortened tails measuring 1 ft 8 in, annular and cruciform guides of Pomortsev's design, and several other types of guides were used.[36] The rockets were launched vertically, and the altitude attained was made a primary criterion for their evaluation. However, since the Nikolaev Rocket Plant possessed no instruments for precise measurement of the altitude, it had to be estimated by the naked eye.

The experiments showed that the signal rockets of accepted design (with a single wooden tail) were no match to the others in altitude and flight precision. The best results were obtained with rockets equipped with Pomortsev guides, which while reaching an altitude 2.5 to 3 times that obtainable with conventional rockets, also flew accurately and stably.

At the time these experiments were carried out, two signal rockets with guides designed by Berezhen, an official of the Nikolaev Rocket Plant, were also launched, both times with very good results. Karabchevskii's report noted that these rockets "flew straight upward and stably, and attained no less altitude than those equipped with Major-General Pomortsev's guides."[37]

About a month later the experiments with signal rockets were repeated, but this time, since it was desired to determine the ranges of these rockets with different stabilizers, they were launched not vertically, but at various angles to the horizon, and from a specially designed stand (Figure 29). The results are given in Table 22."[38]

TABLE 22. Results of Rocket Tests with various types of stabilizers

Type of stabilizer	Launching angle			
	45°	30°	30°	30°
One wooden tail . . .	200/39*	247/4	297/19	Burst
Two shortened tails . .	288/11	303/4	372/41	350/12
Cruciform guide . . .	Not found	Nearby	290/34	383/3.5
Annular guide	327/33	363/19	370/0	395/33

* The numerator denotes the range of the rocket, and the denominator, its lateral deviation from the assigned direction. All measurements are given in sagenes [1 sagene — 7 ft].

It is readily apparent that in this case the rockets equipped with annular stabilizers performed best.

Concurrently with his research for the improvement of solid propellant rockets, Pomortsev was looking for other energy sources for use in rocket projectiles.

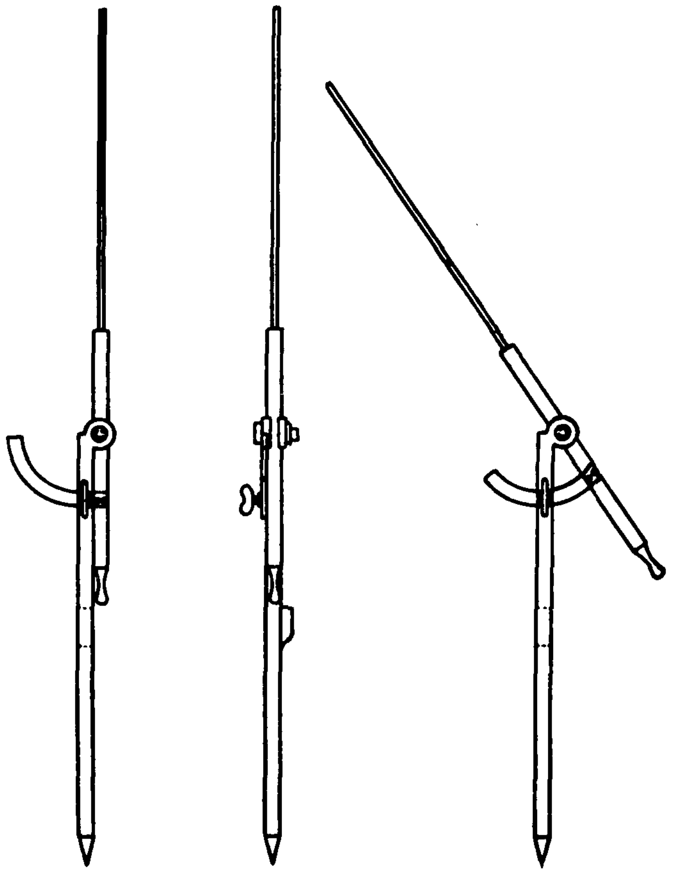


FIGURE 29. Stand for launching of signal rockets.

As early as 1903 he presented to the Artillery Committee a program of experiments in which he expressed the view that one area in which projectiles working on a reaction principle could be improved was "in the development of a new type of rocket, operating not by the combustion of a solid propellant, but by compressed air inside the rocket casing."[39]

"The Mannesmann tubes now used in Germany, England, and France to transport compressed hydrogen for aeronautical purposes," he wrote, "weigh about 70 kg, while each such tube delivers as much as 30 m^3 of hydrogen, compressed to 200 atmospheres. It takes 15 minutes to empty such tubes by means of special valves."[40]

On the basis of these figures, Pomortsev concluded that similar tubes or casings weighing about 10 to 20 kg and delivering air compressed to 150—200 atmospheres could be built. These tubes could be evacuated in 2 to 5 minutes.

"If such casings," Pomortsev continued, "were to be fitted with heavy head pieces, they would resemble aerial torpedoes which, possessing an enormous energy reserve, would be able to cover considerable distances through the air."[41]

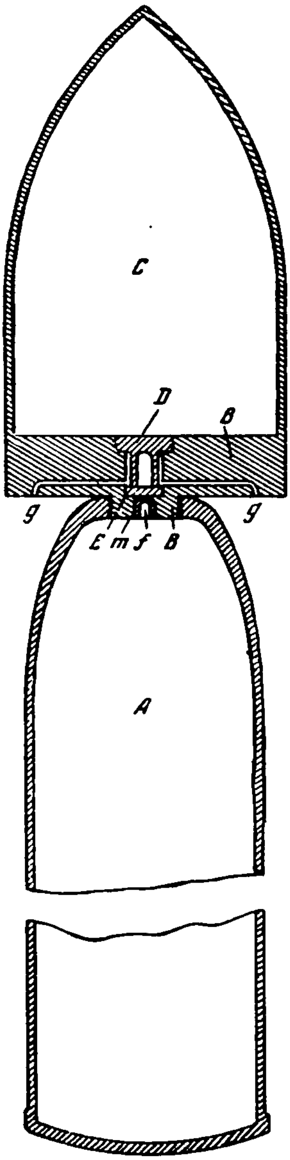


FIGURE 30. Scheme of pneumatic rocket designed by Pomortsev.

In October 1905 Pomortsev put forward a detailed design for a compressed air rocket (Figure 30).[42] A steel tube *A*, able to withstand pressures of above 200 atm, served as reservoir for the compressed air. A steel sleeve *B*, within which were four channels *g* each 2.5 mm in diameter, was screwed into an opening in the pipe *A*. The exhaust openings of these channels were arranged in perfect symmetry about the central axis, and inclined slightly outwards to give freer passage to the compressed air and reduce its friction against the threaded walls of the tube *A*. Inside the sleeve *B* all four channels *g* were joined in a larger channel *f*, leading into the reservoir *A*. The channel *f* was closed off by a small brass cover *m* and an ebonite disk *E*, which was tightly pressed against the flanges within the channel *f* by means of a screw *D*. This screw contained a percussion cap, which upon its ignition by means of an electrical spark, forced an opening in the disk *E*, letting the compressed air into the channels *g*.

Pomortsev thought that this design would promote flight stability, since the point of application of the reactive force was in front of the rocket's center of gravity. To increase stability, the rocket was equipped with stabilizers of the type developed by Pomortsev for rocket flares. The forward part of the rocket (*C*) would hold explosives or some other payload.

Pomortsev also carried out some approximate calculations for this pneumatic rocket.[43] Its weight was 16—17 kg, no more than that of a conventional 3" rocket flare. As compressed-air reservoir he used a steel tube 100 mm in diameter and 1 m long, manufactured by the Montbard plant in France. This had a capacity of 1.5 m^3 of air compressed to 200 atm. Pomortsev's figures indicated that the reactive force would reach 40 kg at the commencement of motion, after which, while gradually declining, it would continue to act for 25 seconds, or almost the entire duration of flight. This feature meant considerable superiority to solid propellant rockets, in which all the energy developed by the gases was dissipated in the first 2 or 3 seconds, after which the rocket moved by inertia, like a ballistic projectile.

The pneumatic rocket design was approved by the Artillery Committee,[44] and in the spring of 1906 Pomortsev was able to begin preparing for the experiments he desired to carry out.

By May 1907 all the equipment required for experiments on compressed-air rockets was concentrated in the chemical laboratory of the Mikhailov Artillery School. However, Pomortsev, before proceeding to the planned experiments, wished to complete his experiments on solid propellant rockets, so as to make use of their results.

Curiously enough, Pomortsev also pondered such factors as the temperature inside the rocket casing. Noting that cooling would result, together with a rapid fall of pressure inside the casing, as the compressed air flowed out, he concluded that it might be better to use compressed air in combination with gunpowder gases, which develop high temperatures during combustion.[45]

In April 1908 the Artillery Committee considered the results of tests of Pomortsev's rockets, and expressed a completely favorable opinion of them, with the comment that their significance was greatly increased by the fact that no serious research on solid propellant rockets had been done for the forty years preceding.

Recalling that even in the middle of the 19th century Konstantinov had persistently adhered to his notion of the importance of scientific research for the further development of rocketry, the Committee emphasized that such development acquired particular value in the period under consideration, because of the perfection of modern artillery pieces. "Therefore, " ran the Committee Journal, "the fact that the experiments of 1907 at the Nikolaev Rocket Plant mark the beginning of laboratory research on rockets is of great importance. "[46]

While admitting that in range Pomortsev's rockets were greatly superior to those of the earlier design (the range of 3" rocket flares with missile-bearing cap, weighing about 18 lb, was 2—3 versts [2300—3500 yd], and that of 3" military rockets with missile, weighing 8—10 lb, was 5—6 versts [5800—7000 yd] and more, while the signal rockets rose to an altitude 2.5 to 3 times that achieved by rockets with wooden tails), the Committee did not agree with his assertion that his stabilizers assured true rocket flight, since this had not yet been established by the experiments.

The Artillery Committee also noted that deficiencies in the launching stand used by Pomortsev were apparent from the very beginning. This stand was so short that the rockets moving on it could not acquire sufficient initial velocity, and as a result frequently deviated sharply from the direction of aiming. Furthermore, the results of the experiments did not lead to development of the best rocket mixture, and the incorrect choice of a dynamometer made it impossible to determine exactly the maximum gas pressure in the casing, as well as the best dimensions for the gas exhaust orifice and the ignition channel.

"The preceding shows, " the Committee Journal continued, "that the experiments performed last year, on rockets fitted with guides, have not yet given conclusive solutions to the problems set for the first phase of rocket research. However, the failures which occurred have resulted in improvements in instruments and rocket casings, so that there is good hope of a satisfactory solution of these problems through continuation of the experiments. "[47]

In conclusion, after observing that the tests which had been performed, being the first experiments of their kind, could not solve a number of the problems confronting the researchers, the Committee noted that they nonetheless provided material for further experiments, and expressed itself in favor of their continuation.

In setting up the program of future research, a great deal of attention was given to the subject of which types of rockets should be tested first. In the previous years, as mentioned above, the tests were extremely varied, taking in rockets differing both in function (military, signal, and flares) and in energy source (gunpowder gases, compressed air).

In 1908, however, the Artillery Committee decided against tackling too many different things at once, and that effort should be concentrated on the testing of rocket flares, propelled by gunpowder gases, as the type then thought to be of the greatest practical importance. At the same time the fifth section of the Committee was assigned the task of reviewing Pomortsev's pneumatic rockets and expressing its views on the advisability of future experiments on them.

Certain specific research goals were also proposed. "The experiments must be begun," ran the committee Journal, "with study of combustion on a dynamometer, in order to determine: a) the importance of the rocket propellant and b) the importance of its uniformity and density of compression. Then, with regard to the design of casings and the projectiles fitted with them, the objects of study should be: a) the influence of the dimensions of the exhaust orifice and b) that of the size of the ignition channel. Study of these factors will require launching of rockets with guides of Major-General Pomortsev's design on the Ochakov proving ground, with proper determination of the places where the rockets fall after shooting. . ."[48] A program of experiments was thus developed and the tests themselves could be begun; but because of some confusion, which arose mainly through financial matters, Pomortsev was actually dismissed from the tests of the rockets which he had designed, and they were conducted at the Nikolaev Rocket Plant without his participation.

During the second half of 1908 Karabchevskii and Demenkov intended to perform a new series of experiments, with the object, as before, of determining the optimum parameters for solid propellant rockets of the type being studied. A great many experiments were performed to determine the gas pressure in the rocket for different combinations of ignition channel dimensions, and number and cross-sectional area of gas exhaust orifices.

The results of these experiments were presented by Karabchevskii in a table,[49] analysis of which brought him to the following conclusion:

"a) A single central gas exhaust orifice is most efficient. . .

"b) It is more efficient for the gases to flow out through six holes and a central orifice, having a total area of 2.7268 sq in, than only through six holes, having a total area of 1.8408 sq in. . .

"c) The most efficient combination is a central exhaust orifice 1.5" in diameter (for which the cross-sectional exhaust area of 1.768 sq in is close to that of the six holes of the 3" luminous rocket now in use) and an ignition channel 0.5" in diameter."[50]

In 1908 no experimental rocket launchings were held, and they were resumed only in April, 1909, when 38 rockets with various types of guides were tested at Ochakov. The former relatively short stands were

replaced by a long cast iron tube, and in a number of rockets the form of the cap with illuminating compound was altered (its length being increased, with a corresponding decrease in diameter). Karabchevskii drew the following conclusions from these tests:

"1) Rockets with caps of the old type have shorter range than those with lengthened caps of smaller diameter, in spite of the fact that the total weight of the old type of cap with projectile is more than twenty pounds less than that of the new cap; this is a consequence of the lower wind resistance of the latter.

"2) Some rockets with guides instead of a tail were true in flight, some underwent considerable deviations from the directrix, and 7 rockets, in leaving the stand, dived into the earth, as if into water.

"3) The range was the same as in the first two launchings at Ochakov, i.e., up to 2.5 versts [2900 yd].

"4) The stand consisting of a cast iron tube, while better than earlier types, requires that 4 incisions be made in the tube along its length in order to fit on the circular guide (the edge from the external ring to the thick ring by which the guide is fitted onto the rocket casing). These parts of the tube are therefore highly unstable and every least jolt they receive is transmitted to the rocket as it leaves the stand, i.e., at the most important moment for acquisition of a correct initial direction."[51]

The results of the 1907—1909 experiments on Pomortsev rockets disappointed the representatives of the Artillery Committee, who expected results "that would resolve the problems of the new rockets to the extent that their mass production could be begun."[52]

As a result, at the beginning of 1910 it was decided to terminate the tests of Pomortsev rockets. "The Artillery Committee," ran the Committee Journal for 27 January 1910, "having been convinced by the numerous experiments conducted at the rocket plant that the guides proposed to replace tails, while increasing the range of luminous rockets, make them less true in flight, would consider it timely to bring an end to such experiments."[53]

Not all rocketry experts shared this opinion, however. Karabchevskii took quite a different view of the experiments, and wrote, in the report which he submitted to the Artillery Committee in 1909:

"The development of the rockets designed by Major-General Pomortsev has so far not led to satisfactory results, and in spite of those successes which have been attained, justify many skeptics who look upon Pomortsev's idea doubtfully; but I make so bold as to assert that this doubt should be directed towards the not altogether satisfactory conditions under which the experiments were conducted, rather than towards the idea itself.

"... It is my personal opinion," he continued, "that Pomortsev's rockets do have a future. This year we shall try to perform a few more launching tests after overcoming the above-mentioned deficiencies, and shall also use a star-shaped guide of steel band, since it will be far easier to design a stronger and most important, stable, launching stand for rockets with such a guide."[54]

Karabchevskii's plans were not destined to be fulfilled, however. In 1910 the Nikolaev Rocket Plant was shut down, and the Artillery Committee conducted no further experiments with Pomortsev's rockets.

In 1912, in his article "Old Experiments and the Modern Data of Aviation" (Starye opyty i sovremennye dannye aviatsii), published in the journal "Tekhnika vozdukhoplavaniya," Pomortsev gave some details of his rocket experiments, pointing out that rockets equipped with stabilizers of his design, and having an overall weight of 10—12 kg, had attained ranges of 8—9 km.[55]

For some time subsequently Pomortsev conducted rocket experiments at the Kuchino Aerodynamic Institute, founded with the funds of D. P. Ryabushinskii, who published their results in 1920, in the 6th number of the papers of the Kuchino Institute.[56]

In the years immediately before the First World War (1909—1912) several attempts were made in Russia to build a new type of military rocket for battle with an enemy airforce. The progress that had been made in aviation and aeronautics by that time gave a sound basis for the belief that the airforce would have a considerable role in future military actions. The designers and inventors of all countries were thus faced with the problem of finding a weapon that would be effective against the airplanes and aerostats of an enemy.

In Russia the first experimental firings of rockets against aircraft took place in 1909 at Sestroretsk, with completely unsatisfactory results. As the Artillery Committee Journal noted, "the bombardment of balloons by rockets had to be utterly rejected, since the experiments revealed the utter aimlessness of such bombardment: the slowness of the rockets and low accuracy with which they were thrown meant that a rocket could not come anywhere near an aerostat, if the latter was in motion."[57]

Later on, N. V. Gerasimov (in 1909—1912), N. A. Sytenko (in 1909—1910), I. V. Volovskii (in 1912) and others worked on anti-aircraft rockets.

The gyroscopic rocket design of the military engineer N. V. Gerasimov is of the greatest interest. After consideration of the possible means of attacking enemy aircraft, he reached the conclusion that a direct hit would be extraordinarily difficult to achieve. He therefore suggested using mine shells filled with such explosives as melinite, ecrasite, pyroxylin, etc., to strike, not the aircraft itself, but the space in which it moved. Gerasimov considered rockets the most suitable means for hurling such missiles, were it not for the drawback of their highly unsatisfactory accuracy. Rockets could not be considered a serious form of weapon before removal of this fundamental deficiency.

After study of the characteristics of rocket flight, Gerasimov concluded that "the chief causes of their low accuracy consisted of:

"1) the instability of the rocket's major axis during aerial flight;

"2) the excessive lengths of rockets, which reached 25 calibers (including the tail);

"3) the transfer of the system's center of gravity as the rocket propellant burned; and

"4) the inferior preparation of the rocket propellant, gradually stuffed into the casings through very long tubes."[58]

Gerasimov designed a rocket which he felt to be free from all the characteristics having an undesirable effect on flight accuracy. Most of his attention was devoted to the attainment of flight stability, for the sake of which he designed a special type of stabilizer.

"The rocket's major axis, " wrote Gerasimov, "will be stabilized by the rotation within it of two turbine wheels constituting a gyroscope. Their velocity will be such as to give the rocket axis the same stability as that of a missile shot from a gun. The turbines are made to rotate by the gases liberated through combustion of the rocket propellant, and the axis is stabilized before the rocket begins to move along the tube of the launching stand. After burnout, the rotational velocity of the turbines will be maintained by air entering through an orifice in the head of the rocket and moving very rapidly due to the difference in air pressure on the head and the bottom of the rocket, which results from its swift motion through the air. The use of a turbine always imparts stability to the axis about which the rotation takes place, and it cannot therefore be doubted that the axis of the rocket will be sufficiently stable. "[59]

Gerasimov's gyroscopic rocket (Figure 31) had two main parts: a cylindrical casing *a*, containing the rocket propellant, and a gyroscope compartment *b*.[60] The cylindrical casing, 170 mm in internal diameter, was made of 3-mm steel. It contained three cylinders of compressed rocket propellant in file, with a cylindrical channel of such dimensions as to give a combustion surface of 1500 cm^2 (according to Gerasimov's figures, enough to form the quantity of gases required to set the rocket in motion).

The cylinders burned successively, beginning with the lowest one, placed alongside the gyroscope. The upper covering of the casing *a* simultaneously served as a bottom for the chamber containing part of the explosive, the remainder of which was located in a lower chamber behind the turbines. Below the casing *a* was closed off by the base plate *b'*, which also served as a roof for compartment *b*. The base plate was fitted with a movable bottom *S* with six orifices with tubes *l* for emission of the hot gases. The movable bottom was maintained in the upper position (Figure 31, section along *AB*) by six cylindrical springs *r*, with a pitch of 10 mm, so designed that when the pressure in the casing reached 2—3 atm, the movable bottom began to descend, reaching its lowest position at a pressure of 5 atm.

The tubes *l* descended with the movable bottom, and as they did so, the lateral orifices *p'*, through which the gases could escape directly into the air, began to open. As the bottom descended (with increase of pressure in the casing) an increasing proportion of the gases escaped into the air and only a tiny part entered the channels of the turbine wheel *z*. As Gerasimov noted, the area of the orifices *p'* had to be so calculated, in accord with the quantity of gases liberated, that the pressure inside the casing did not exceed a previously established limit, approximately 10 atm, beyond which bursting of the casing would result.

After complete combustion of all three cylinders air began to enter the casing through the orifice *y* (Figure 31) which had opened in the head of the rocket. Since the pressure in the casing was decreasing, the movable bottom began to rise and occupied such a position that the lateral orifices were closed, so that all the air entered the channels feeding the turbine.

Gerasimov thought that this design would assure rocket firing accuracy equal to that of fire from heavy ordnance. He added that the velocity and

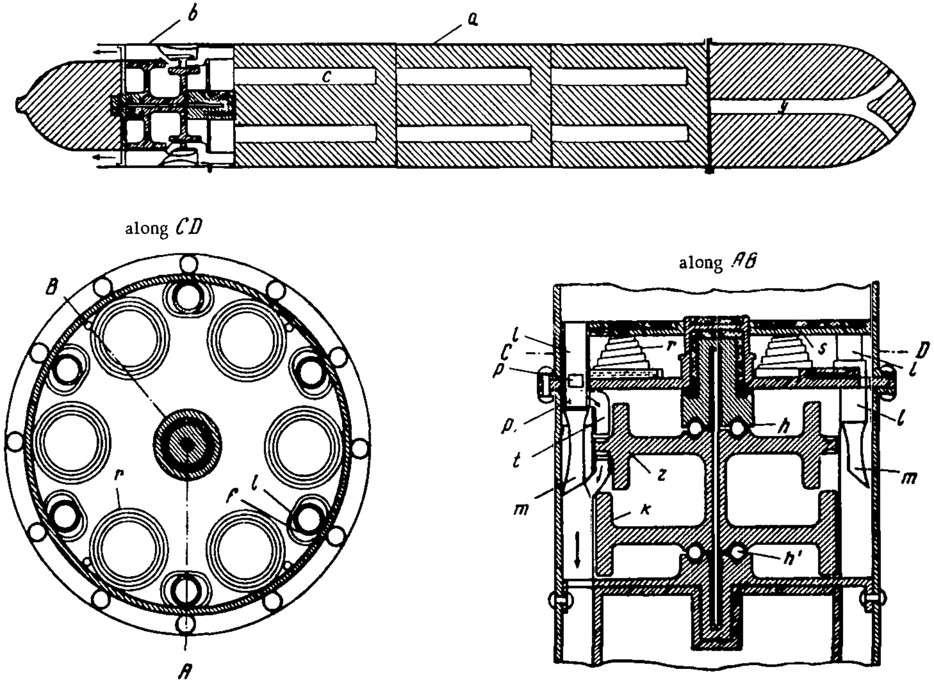


FIGURE 31. N. V. Gerasimov's design for a gyroscopic rocket.

range of rockets could be considerably increased by using a perfected rocket propellant and more efficient use of the combustion period.

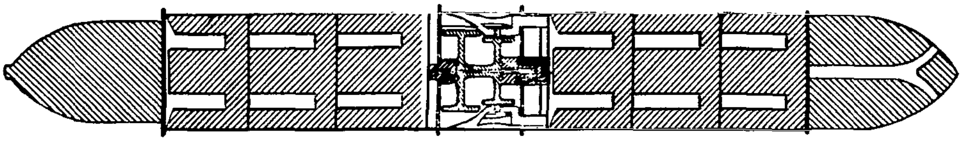


FIGURE 32. Gerasimov's gyroscopic rocket design (second version).

Gerasimov also developed another version of the gyroscopic rocket (Figure 32), which differed from the first in having the gyroscope at the system's center of gravity, as well as in turbine wheels of different form. The subdivision of the rocket propellant into two parts made it possible to decrease the height of the powder charges (from 24 cm to 13 cm), while the displacement of the system's center of gravity by combustion of the propellant was thus reduced from 28 mm to 17 mm. The drawback of this second version, in Gerasimov's opinion, was "some loss of the propulsive power of the gases formed by the front cylinders, which had to change their direction somewhat."[61] Gerasimov gave the velocity of his rocket as 400 m/sec, with a range of 8—9 versts [9500—10,500 yd]. The weight of the rocket, totaling 61 kg, was broken down as follows:

Casing and other parts	19 kg
Rocket propellant	24 kg
Explosive in projectile	13 kg
Gyroscope	5 kg
Total weight of rocket	61 kg

Gerasimov did not only intend to use his gyroscopic rocket to attack enemy aircraft, but also to propel aircraft, i.e., as an aviation engine.

In October 1909 he patented (No. 40945), and in February 1912 received License No. 21024 "for a device to propel aircraft," which, as noted in the patent application incorporated the following components: a) a gas generator *a* with annular chambers *c*, filled with combustible material; b) a gas reservoir with movable bottom *S*, from which branch pipes *l* with apertures *p* and *t′* led to the nozzles *t*; c) jackets *f* surrounding the branch pipes *l* and equipped with the nozzles *m*; and d) two coaxial turbines *z* and *k*, located in the chamber *b* and successively fed by the gases leaving the nozzles *t*, the gases released by the second turbine pushing the machine forward.

Gerasimov's design was not built, but nonetheless clearly appears to have been a sort of prototype of the modern turbojet engines now in such widespread use.

Gerasimov was a fervent advocate of military rockets and had sound insight into the future of such weapons. "Rockets," he wrote,

"will permit man, while remaining on earth, to rule also in the skies, since rockets, beyond doubt, will always be able to fly faster and higher than any other aircraft controlled by man."[62]

Gerasimov did not feel that the applications of gyroscopic rockets were confined to action against enemy aircraft, but believed that they could also find use in the field, in the defense of fortresses and in naval battles. He also thought that "in the very near future rockets will replace all cannon of caliber above 6", since the advantages of a cheap, light, recoilless rocket stand which does not wear, over a heavy, expensive, short-lived cannon, are too great."[63]

Gerasimov particularly emphasized the unquestionable advantage of replacing heavy artillery by rockets for Russia, which was behind the leading European countries in the development of the former. "By this means," he wrote, "we shall not only catch up with Europe, but in strength of armament might even precede her."[64]

The special commission appointed by the Chief Artillery Administration after consideration of Gerasimov's proposal, expressed doubt that "his rockets will be in a position to compete with the artillery projectiles in current use in accuracy and range."[65] The commission nonetheless decided: "It can be assumed that with the rocket launching stands now in use and modern forced propellant the rockets of Councillor of State Gerasimov will prove superior to existing ones in flight stability, and it will therefore be of use to perform experiments with them in order to make peferctly clear how the internal gyroscope affects their trueness in flight."[66]

The decision of the commission was also influenced by the increasing urgency of finding means to oppose enemy aircraft, and the desirability of investigating the applicability of gyroscopic rockets for this purpose was also mentioned.

Wishing, however, to reduce expenses for the conducting of experiments, the commission urged the use, at least at the beginning, of standard 3" rocket flares with the forced propellant used for them, since retooling of the rocket plant's workshops would be required to fill casings of greater caliber, and this would involve considerable expense. At the same time, realizing the complexity of manufacturing a gyroscope of small diameter, the commission proposed placing the conventional 3" rockets to be used in the initial experiments inside special casings of large diameter, to the bottom of which the box containing the gyroscope was attached.

At the end of 1909 Gerasimov prepared to perform the preliminary experiments, in which he intended:

"1) to study the properties of rocket gases; 2) to develop mechanism designs; and 3) to test the firing accuracy of the rockets, for this purpose adapting a gyroscope to conventional 3" rockets."[67]

At first the experiments were conducted in France, and afterwards (from February 1910 onward), at the Main Artillery Proving Ground in Petersburg. The first series comprised determination of the pressure developed in the combustion chamber, and the thrust of the rocket (Gerasimov termed these respectively internal and external pressure). The measurements were made with Richard automatic recorders.

The pressure inside the combustion chamber was measured as follows. In place of a tail, a curved steel cylinder with a channel 12 mm in diameter was screwed into the base plate of the rocket. A steel tube 500 mm in

length, which was joined to a brass tube, also 500mm in length, led from the cylinder to a manometer. The brass tube was connected directly to the manometer, designed to measure the internal gas pressure of the rocket and mounted upon a special table, separated from the rocket by a low earth embankment.

A dynamometer with hydraulic pressure transmission, for measuring thrust, was on the same table. The rocket being tested was fastened to iron rings at the base of a vertical stone wall, to which was attached a hydraulic receiver. A tube about 2m in length led from the receiver to the table with the dynamometer. Both the manometer and the dynamometer were carefully calibrated by the Richard firm. The propellant was ignited by electrical igniters. The graphs obtained from the experiments were verified and signed by Gerasimov and the plant director.

The first experiments, conducted in November 1909, did not give the data required, since soon after beginning the tests the brass tube burned through, and, in a repetition of the experiment, so did the thin-walled steel tube used to replace it.

Gerasimov tested four rockets during the second experiment in December of the same year. This time all went well, and four graphs of thrust vs. time were obtained. Only three graphs of combustion chamber pressure were obtained, the fourth being lost through faults in the recording mechanism.

Analysis of the curves led Gerasimov to the conclusion that the thrust of a rocket depends:

"1) on the amount of gases liberated by combustion of the propellant in a given period of time;

"2) on their minimum velocity in the orifice; and finally

"3) on the time it takes the gases to acquire this velocity."[68]

The experiments conducted at the end of 1909 and beginning of 1910 showed that the pressure developed in a 3" rocket does not exceed 18 atm, and that the thrust of the rocket reaches about 180kg and is not directly proportional to the combustion chamber pressure. In February and March 1910 Gerasimov conducted a series of new experiments with his gyroscopic rocket, but this time the results showed that the use of his gyroscope with the 3" rockets standard in Russia did not provide sufficient angular velocity to give the rocket the required stability.

As noted in Gerasimov's memorandum to the Artillery Committee, the rocket axis could be stabilized only when the gyroscope rotated with an angular velocity of not less than 300 rps, while in 3" rockets the short period of time for which the gases acted on the gyroscope (only 1.25 sec) gave an angular velocity of only 79 rps. Gerasimov thought that the required angular velocity could be attained if the number of orifices were doubled, and the period for which the gases acted on the gyroscope increased to 4 sec.

During the following two years (from June 1910 to June 1912) Gerasimov continued his tests, but without success, as before. From December 1910 to July 1911 the experiments, which comprised stand testing of rockets as well as launchings, were conducted by the experimental commission of the Okhtensk Gunpowder Plant and at the Main Artillery Proving Ground. All of the rockets tested burst on the stand and the gyroscope did not even begin to rotate.

As a result, Gerasimov again altered his rocket design, placing the small cylinder intended to set the gyroscope rotating on the stand inside an iron cap screwed onto the bottom of the rocket. Upon the combustion of this cylinder the gases then flowed exclusively into the gyroscope compartment; ignition of the large cylinders occurred through an opening in the cover of the iron cap.

The new experiments, however, conducted between January and April 1912, continued to give negative results: the rockets either burst on the chute, burned out without leaving it, or covered an insignificant range of no more than about 70 sagenes [165 yd].

As a result, Gerasimov again altered the design, at the end of April 1912. The small cylinder was brought out behind the bottom, and the gyroscope served as its continuation; as before, the gases from the large cylinders did not act upon the gyroscope. The first experiment with this rocket resulted in explosion of the propellant cylinder, as a result of which the cylinder was solid-drawn. At the same time Gerasimov proposed to replace the previously used propellant (52% nitrates, 18% carbon, 30% sulfur) by the stronger one used in Russian 3" rockets. The last tests, conducted in June 1912, also failed to give positive results.

The extensive factual material on the tests brought the Committee appointed to consider Gerasimov's gyroscopic rocket to the following conclusion:

"Both the preliminary experiments on stationary rocket ignition (with instrument determination of propulsive force and internal pressure) and those on launching from a stand or open chute have so far given no even faintly satisfactory results, such as some attainment of range (however short) and flight precision (in both of these areas these rockets have proved inferior to our 3" luminous rockets of old design).

"It is impossible to decide whether the design of the rocket's metal parts, its equipment, or the choice of propellant is to be blamed for these exclusively unfavorable results, but in any case, the rocket as a whole, together with its launching stand, must be regarded as insufficiently developed. There are virtually no indications, however it may have seemed a year and a half ago, that positive results can be obtained by continued experimentation with it."[69]

During the period of Gerasimov's experiments, the engineer N. A. Sytenko (in 1909—1910) and I. V. Volovskii, the former assistant director of the Putilov plant (in 1912) were also developing designs for anti-aircraft rockets.

Sytenko's aerorocket (Figure 33) was designed for strikes against dirigibles and airplanes and was to consist of five or six Congreve rockets joined together, but sharing a common tubular tail.

The aerorocket was intended to be ignited in such a way as to fire all the separate rockets composing it simultaneously. For this purpose the upper part of the rocket stand's connecting piece was fitted with a magnetic igniter which supplied a spark to all of the component rockets simultaneously. The rockets' warhead was to consist of shrapnel, which would readily inflict damage on enemy aircraft.

"These rockets, with their stands," Sytenko wrote, "can be placed en masse along demarcation lines at a small distance from one another, and in time of war, when convenient, can be launched by the frontier guards."[70]

The Artillery Committee, however, after consideration of Sytenko's design, expressed the view that the combination of several rockets would result in a worsening, rather than an improvement of ballistic qualities, since some increase in the thrust would be accompanied by an increase in air resistance due to the enlarged cross-sectional area of the aero-rocket. It also felt that a further cause of nonuniformity — the unequal combustion of the forced propellant in each of the rockets grouped about a common tail — would adversely affect flight precision.

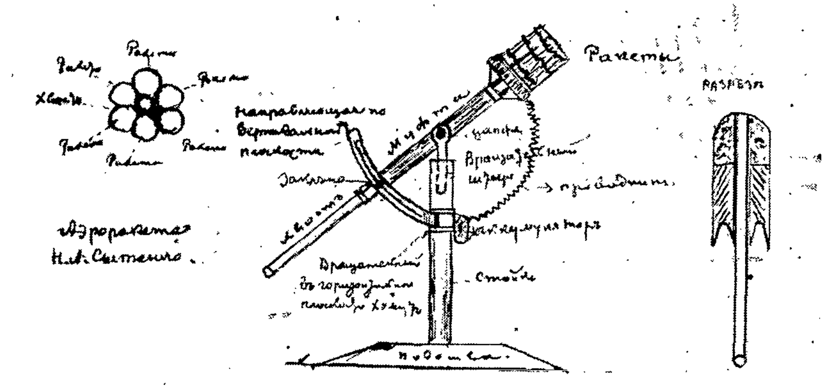


FIGURE 33. Aerorocket designed by N. A. Sytenko.

"Furthermore," the Committee Journal continued, "the increased weight and volume of the head of such a combined rocket will have to be balanced by extremely long and heavy tails, greatly complicating the launching stands and increasing their weight, if the conditions normally accepted are to be satisfied: namely, that the center of gravity of the rocket be near its casing, and that the center of air resistance be near the center of the rocket's over-all shape and below its center of gravity."[71]

As a result the Artillery Committee, finding Sytenko's aerostat unsuitable for attacks on enemy aircraft, rejected his project.[72]

In April 1912 Volovskii presented to the War Department a design for a military rocket (Figure 34, Type No. 1), as well as designs for two launchers for launching rockets from automobiles and airplanes.[73]

Volovskii proposed to increase range and accuracy by substituting for the wooden tail a hollow metal tube, an extension of the rocket casing, and by using radially placed planes slightly inclined to the axis of the tube to make the rocket rotate.

The Artillery Committee rejected Volovskii's project. The Committee Journal commented that both of the means he proposed for increasing range and accuracy were not new and had been tested repeatedly both in Russia and in other countries: "... Volovskii's proposal is not at all innovatory and in itself does not constitute a technically well worked out project." The conclusion was, "In view of the forthcoming experiments with more fully developed rocket designs based on the same principles,

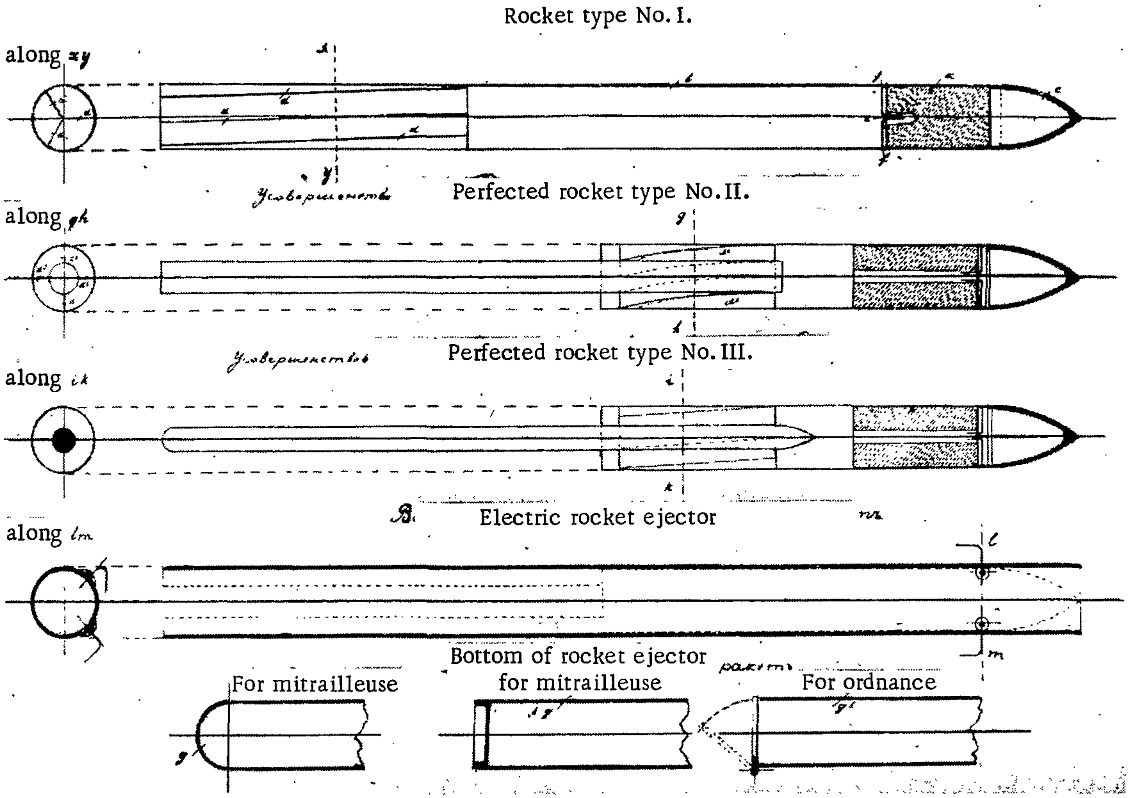


FIGURE 34. I. V. Volovskii's rocket design.

as well as the comments made above and to be found elsewhere in literature on the subject, the Committee feels that the conduct of any experiments whatsoever with this rocket would not be of such interest as to justify the expenditure they would entail."[74]

D. D. Kuz'min-Korovaev, Head of the Chief Artillery Administration, however, did not agree with this opinion and added the following resolution to the Committee's conclusion: "The idea of using rockets as a weapon against aviators is new, and experiments should therefore be conducted with Volovskii's rockets, regardless of their cost."[75] On the basis of this resolution, the War Department decided to inquire of Volovskii what ten rockets of his design would cost, with a view to conducting experimental shooting of these rockets at aerial targets jointly with the Airforce.

Volovskii, meanwhile, had been working to improve his rockets. One of the most serious objections made by the Artillery Committee had been that in Volovskii's scheme the rocket acquired its rotational motion at the cost of a reduction in thrust, which in turn would inevitably result in shortened range.

To counter this, Volovskii proposed to shorten the tail tube, an extension of the rocket casing, considerably, and to install a second tube of smaller diameter, but greater length, inside it (Figure 34, Type No. II).[76] The tubes were joined by four tie rods *d′*, set at a certain angle to the axis of the rocket. The cross section of the rocket was thus divided into two parts: an internal solid one, for passage of the gases whose ejection produced the rocket's forward motion, and an external annular one, for passage, through the four channels formed by the tie rods, of the gases giving the rocket its rotational motion.

The division of the rocket's cross section into two parts had the following advantages, according to Volovskii: by changing the orientation angle of the tie rods *d′*, the rotational velocity of the rocket could be changed, while change in the diameter of the internal tube (the rocket tail) made it possible to establish a ratio between the areas of the internal (solid) and external (annular) parts, thus regulating the amount of gases destined to impart translational and rotational motion, respectively, to the rocket.

Volovskii developed one more version of the rocket (Figure 34, Type No. III), intended for grazing fire from airplanes against cavalry, as well as against enemy aircraft.

This version, identical with type No. II in its dimensions, differed from it in that the internal hollow tube which served as the rocket tail was replaced by a solid wooden bar somewhat less in diameter than the internal tube. As a result the area of the external part of the cross section was increased, though it was still, as before, smaller than that of the entire cross section. The intensity of the gas outflow was therefore increased. Varying of the inclination of the four tie rods so as to make the force of translational motion considerably greater than that of rotational motion, Volovskii remarked, would give the rocket the flattest flight trajectory.

In November 1912 Volovskii's rocket design with the alterations he had introduced was considered for a second time at a session of the Artillery Committee, which, after repeating its earlier opinion that "there are not sufficient grounds to expect it to give greater range or accuracy than the old model rockets currently in use," nonetheless thought it possible to give the inventor means for a practical experimental check of his calculations,

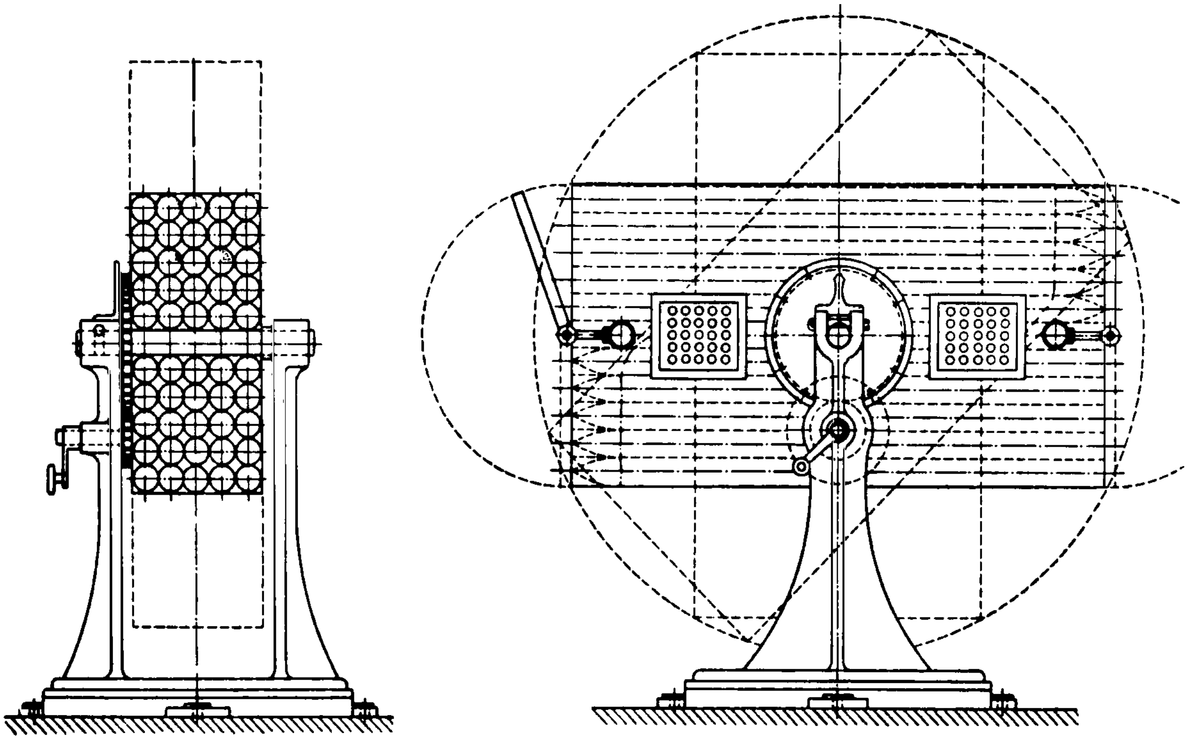


FIGURE 35. Design of a rocket battery for shooting from automobiles.

in view of the great interest manifested most recently in the development of the most perfect type of rocket.[77]

Volovskii's attempt to build a stand for simultaneous launching of several rockets is also of interest as a prototype of future multi-barrelled rocket launchers. He also developed schemes for a rocket battery to be installed on an automobile, and a rocket mitrailleuse for installation on airplanes.

The rocket battery (Figure 35) consisted of a certain number of ejectors (equal to the number of rockets), arranged in straight rows in the form of a square and enclosed in a common shell (jacket). The spaces between the ejectors were filled with some light fireproof material. Each ejector was equipped with two contacts, wired to the energy source.

When the rockets were placed in the launchers (ejectors), contacts located on the forward part of the rockets touched the contacts on the ejectors. When this happened a corresponding bulb on the control panel lighted up. After launching of the rocket the contact was broken and the bulb went out. This made it possible to tell at any time how many rockets were ready for launching, and which they were.

The layout of the rocket mitrailleuse for shooting from airplanes (Figure 36) was roughly similar, except that it did not require a cumbersome gun carriage and was considerably lighter.[78]

A look at the experiments done in Russia at the period under consideration shows that designers and inventors working to improve solid propellant reaction projectiles at the beginning of the 20th century faced much the same problems as had existed at the middle of the preceding century: increasing range and accuracy. However, the progress attained in the various fields of engineering made possible the resolution of many of the earlier problems at a much higher technical level.

One of the most important factors determining the thrust of a rocket engine is, of course, the gas pressure in the combustion chamber, i. e., in the cases presently being considered, in the rocket casing.

The experiments performed in the 19th century did not make it possible to determine the pressure in the rocket casing, but the tests performed at the beginning of the 20th century showed that the casings of the earlier design, manufactured at the Nikolaev Rocket Plant, could withstand pressures not exceeding 80 kg/cm^2.

The use of seamless steel casings made it possible to increase the pressure in the combustion chamber (rocket casing) to 300 atm, which in turn allowed a considerable increase in the reactive force.

The use of seamless casings permitted the solution of yet another problem existing since the 19th century — the construction of rockets with one central exhaust orifice, which in turn permitted further increase of the pressure inside the casing.

Rocket stabilization was perfected. Most of the designs of the latter 19th century and beginning of the 20th are characterized by the rejection of wooden tails and their replacement by either a hollow metal tube, an extension of the rocket casing (Andreev, Pomortsev, Sazanov, Volovskii), or another form of stabilization, such as supporting surfaces (Pomortsev), a gyroscope (Gerasimov), or rotation of the rocket itself (Volovskii).

A serious deficiency of all these designs was their continued use of such a relatively low-calorific fuel as smoky black powder as energy source.

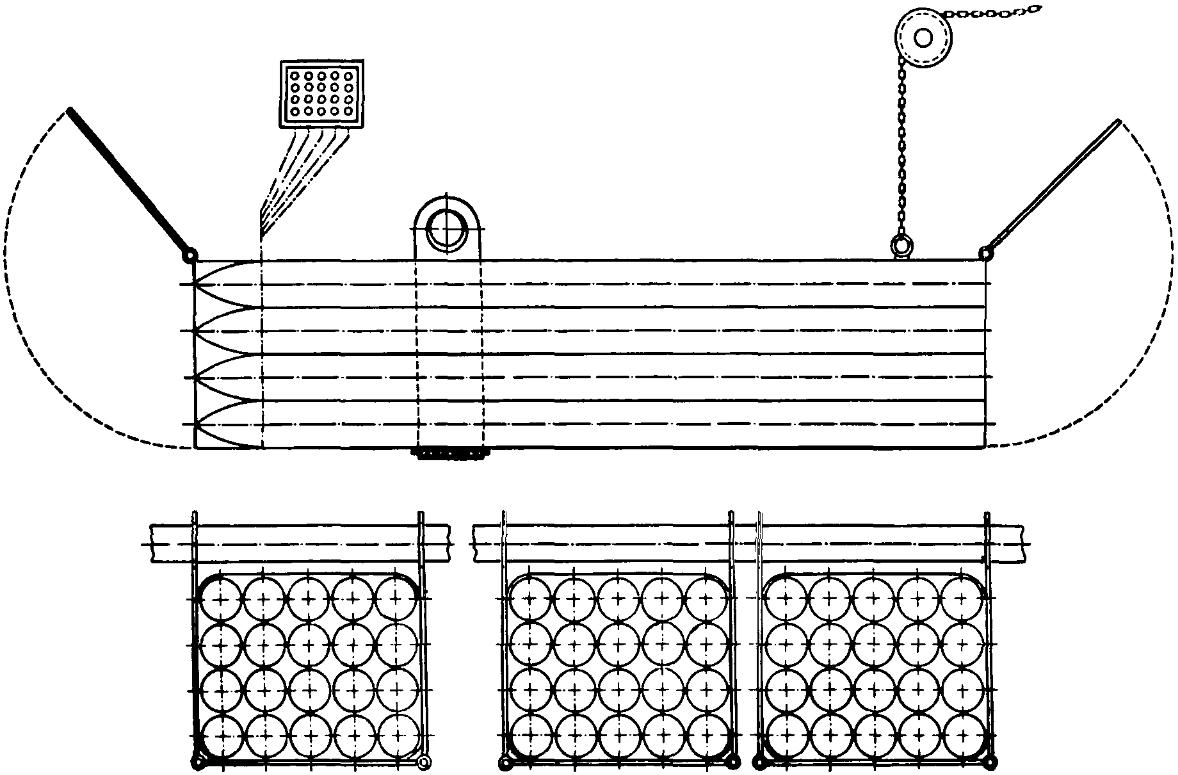


FIGURE 36. Design of rocket mitrailleuse for shooting from airplanes.

As a result of this, in their tactical and engineering characteristics most of the rockets of the beginning of the 20th century essentially differed very slightly from Konstantinov's designs of the mid-19th century.

Further improvement of rocket projectiles required the substitution of some superior fuel for smoky black powder. It proved possible to do this, however, only in the 1920's and 1930's, when a new era in the development of solid propellant rockets began.

ROCKET PRODUCTION AT THE SHOSTKA GUNPOWDER PLANT. USE OF ROCKETS IN THE FIRST WORLD WAR

Transfer of rocket production to the Shostka Gunpowder Plant was discussed as early as 1905, mainly because of financial considerations. A memorandum of the Inspector of Gunpowder Plants noted, "The transfer of the rocket plant to Shostka will not, it seems, occasion any great simultaneous expense, but the abolition of the Nikolaev rocket plant will in any case be a highly economical measure, since a few years of operation with a surplus will cover the expenses involved in transfer of the plant."[79]

It was assumed that casings and all their metal parts would be manufactured in separate plants, and that only assembly, filling, and finishing of the rockets would take place at the Shostka plant.[80]

The decision to transfer rocket production to the Shostka plant, however, was made with excruciating slowness. The office of the Inspector of Gunpowder and Rocket Plants exchanged correspondence with the Chief Artillery Administration for a number of years while budgets and lists of the number of workers involved in an annual production of 4000 and 9000 rockets, respectively, were compiled. Only in November 1909 did the War Council officially confirm the proposal of the Chief Artillery Administration to shut down the Nikolaev Rocket Plant and transfer production to the Shostka Gunpowder Plant.[81]

Dismantling of the Nikolaev plant and equipping of a rocket workshop in the Shostka plant occupied most of 1910, and were completed only in October of that year. The Nikolaev plant was finally closed, while the Shostka plant received an order for 6700 rocket flares to be manufactured during 1911.[82]

Experimental research on rocket flares continued in the period preceding the First World War. The experiments conducted by D. V. Sazanov, former assistant to the Head of the Nikolaev Rocket Plant, and V. I. Ennatskii, Secretary of the Artillery Committee, are of particular interest.

Sazanov began to work on rocket flares in 1907. After pointing out the shortcomings of the current design, which in his opinion were summarized by the impossibility of making the rocket tail and the exhaust orifices in the base plate strictly symmetrical about the rocket axis, Sazanov proposed a radical departure from such a design, substituting for the tail an elongated casing with dimensions to be chosen so as not to alter the weight of the rocket.[83]

This too will readily be recognized as a version of Andreev's proposal, but again without any reference to his work. However, it is not known whether Sazanov had some opportunity to become acquainted with Andreev's design, or simply developed it independently.

At the same time Sazanov put forward another type of rocket without base plate or tail, which featured, in addition to the elongated casing, gradual change in the diameter of the ignition channel.[84] By an appropriate choice of diameter for different sections of the ignition channel, Sazanov expected to obtain the maximum possible range for his design and the rocket propellants then available.

The Artillery Committee, after consideration of Sazanov's proposal, thought it worthwhile to test his rockets, commenting, "Without a base plate, which impedes the flow of gases out of the casing and has orifices of limited area for their passage, it will in all probability be possible to increase somewhat the length of the channel, thereby increasing the gas pressure in the channel, and giving the rocket greater velocity and accuracy in flight."[85]

The experiments, however, could be begun only in 1909, shortly after it was decided to shut down the Nikolaev Rocket Plant. The rockets actually tested differed substantially from those originally put forward by Sazanov.

The rockets tested in 1909 (Figure 37),[86] consisted of a metal (steel or iron) casing, to which was attached a cap containing an incendiary compound and two lateral wooden tails. At one end the casing was closed off by a metal disk with a depression into which the cap could be screwed. An aperture for a time-fuse was left in the center of the disk. Two pairs of metal clamps served to couple the tails to the casing.

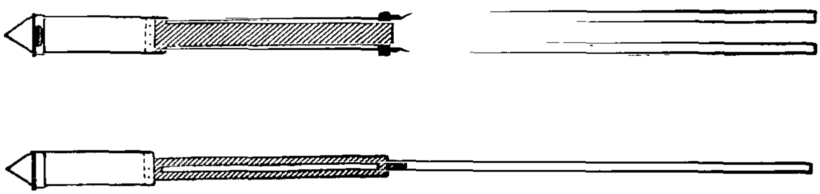


FIGURE 37. Rocket designed by D.V. Sazanov.

As Major-General Rudakov, assistant to the Head of the Shostka Gunpowder Plant, later observed, the features of Sazanov's rocket design were the following:

"1) The absence of a base plate,

"2) a long, narrow cap for luminous pellets,

"3) two tails, placed along the two generatrices of the casing, rather than one, located along an extension of the rocket axis,

"4) chalk and sulfur are not rammed in,

"5) a time-fuse ready for use is screwed into the rocket plug,

"6) a cap, also completely finished and equipped with pellets, is screwed into the same plug."[87]

The experiments were conducted in April 1909, at the Ochakov proving ground. Altogether 6 rockets were launched, and ranges of 2100 to 2500 m were achieved, with lateral deviations of from 0 to 200 m.[88]

In addition, Sazanov conducted stand tests of rockets in which the length of the ignition channel had been increased to 39", while the diameter

remained at 1", replacing the propellant by compressed black powder. In neither case did a burst casing occur, so that Sazanov had a case for proposing the introduction of these changes into the rocket flares of his design.

While developing rockets for purposes of illumination, Sazanov also devoted thought to the application of his rockets as military projectiles. He noted that if the cap with 20 pounds of incendiary mixture (measuring 4 5/8 by 21 inches) were to be replaced by a cylindrical pointed missile weighing 10 pounds, and measuring 3 1/8 by 11 1/2 inches, the range of the rocket would rise from 3 to 5 versts [3500 to 5800 yd], and it would be suitable for the bombardment of fortresses, camps, villages, and other more or less sizeable areas.[89]

The Artillery Committee, after consideration of the experiments on Sazonov's rockets (with lengthened casing, without base plate, and with two lateral wooden tails), concluded that it would be worthwhile to continue the experiments, since the preliminary results had been satisfactory. "The range was greater than that of luminous rockets currently in use, flight accuracy was reasonably well preserved, and the stationary combustion of rockets with compressed black powder gives some indication of its feasibility in place of weaker rocket propellants."[90]

The Artillery Committee Journal emphasized the particular desirability of replacing the rocket propellant by compressed black powder in view of the proposed transfer of rocket production to the Shostka Gunpowder Plant, since it would release the plant from the need to prepare special rocket propellant when standard smoky powder could be used. It was therefore decided to resume the experiments at the Shostka, rather than the Nikolaev plant, but only after rocket production had been properly launched at the former.

The rocket workshop of the Shostka Gunpowder Plant began production in 1911, but the manufacture of the Sazanov rockets dragged on, and the first 20 experimental rockets were ready only by 1913.

The results of the tests were completely unsatisfactory; of seven rockets, only one attained a range of near 2.5 km, while in all the other cases the casings burst due to excessively high gas pressure.[91] Further tests of the series of rockets produced at the Shostka plant were therefore abandoned.

The professionals present at these experiments attributed the burst casings to the great difference in the properties of the powder manufactured in the Shostka Gunpowder Plant and that of the Nikolaev Rocket Plant. Major-General Rudakov, assisted to the Head of the Shostka Plant, reported its powder to be half again as powerful as that of the Nikolaev plant.[92]

It was therefore decided, despite the patently unsatisfactory outcome of the first tests, to continue experimentation on Sazanov's rockets after approving a different rocket propellant and making some alteration in the dimensions of the ignition channel.[93] The matter dragged on, however. until the beginning of World War I.

Ennatskii, who, as noted above, had been sent to Nikolaev in 1907 to participate in the tests of Pomortsev's rockets, began to work on rocket flares at almost the same time as Sazanov. Analysis of the 1907 tests brought Ennatskii to the conclusion that Pomortsev stabilizers would not

lead to development of a satisfactory design for rocket flares in the near fugure, and he therefore urged further attempts at stabilizing rockets by making them rotate.

"It would seem possible," he wrote in September 1907, "to make a rocket fly straight by making one of its components rotate — a special wing (like a paddle wheel on boats), fastened to the casing. This wing would be made to rotate neither by air resistance, nor by the gases giving the rocket its translational motion, but by either an appropriate modification of the stand or, more correctly, by means of work stored earlier (for example, by winding a spring), which is released by a special catch on the stand at the moment the rocket is launched."[94]

Since he realized, however, that the introduction of serious alterations in rocket design would require considerable time, and wished to produce well-functioning rocket flares as soon as possible, Ennatskii at first limited himself to only the most essential changes. In September 1908 he requested from the Artillery Committee permission to experiment with 3" rocket flares of somewhat modified design.[95]

Ennatskii proposed to retain the essentials of the accepted Russian design for rocket flares, i.e., their major dimensions and overall shape, means of stabilization, propellant mixture, fill density, dimensions and number of orifices in the base plate, introducing only the following slight changes:

"1) a) Decrease the diameter of the cap and make its cover ogival in shape;

b) install a means of filling the cap with small pellets.

"2) Adapt the wooden tail to the modified rocket.

"3) Give the ignition channel different, more efficient dimensions."[96]

Ennatskii expected by these changes to obtain an increase in range to two versts [2350 yd], as well as improved accuracy. The preliminary experiments, performed between June and August 1910 at the Main Artillery Proving Ground, with rockets termed Type No. 2, confirmed his estimates, and the Shostka Plant was ordered to build 100 Ennatskii rockets of 2 km range for the conduct of further experiments.[97]

At the same time the Artillery Committee voiced the desirability of a rocket design for illumination at both small and great distances. In December 1911 Ennatskii accordingly presented designs for three types of rockets designed for ranges of 2.5 km (Type 1), 3.5 km (Type 3), and above 5 km (Type 4).[98] In this instance too, however, construction of the experimental rockets proceeded at a snail's pace and according to some accounts was not finished before 1916.[99]

It is of interest that not long before the First World War an attempt was made at the Shostka Gunpowder Plant to find criteria for evaluating rockets of different designs. Major-General F. N. Rudakov suggested using as an index a so-called design coefficient, by which he meant the ratio of the useful work (which he gave as the product of payload weight and flight range) to the weight of the propulsive load. The design coefficient was thus determined by the formula

$$R = \frac{C \cdot S}{D} = \frac{(P - D) \cdot S}{D},$$

where R is the design coefficient of the rocket,
C is the payload weight,
S is the range of the rocket,
D is the weight of the propulsive load, and
P is the total weight of the rocket.

Rudakov made this relatively simple formula the basis of a comparison of standard 3" rocket flares with Sazanov and Ennatskii rockets (Table 23),[100]

TABLE 23. Comparative data on different rocket flares

	Standard 3" rocket flare	Rocket flare designed by Ennatskii	Rocket flare designed by Sazanov
Payload (illuminating compound) in kg	6.8	4.1	6.6
Propulsive load in kg	10.1	9.4	15.3
incorporating:			
rocket propellant	3.9	3.8	7.1
empty casing	2.6	2.6	4.2
sulfur	0.6	0.9	—
cap (empty)	1.4	1.1	1.6
rocket tail	1.6	1.0	2.4
Range in m	1214	2130	2350
Useful work in kg-m	7192	8733	15510
Design coefficient	705.1	929.1	1013.7

Note. The measures in the table have been converted to the metric system.

and concluded that Sazanov's rockets had the best design coefficient, followed by Ennatskii's, while the standard rockets had the poorest. A glance at Rudakov's formula shows that he incorporated in the propulsive load not only the fuel (rocket propellant), but also all of the rocket's structural elements. It was therefore essentially the total starting weight of the rocket, excepting only the payload. This approach aroused the objections of the Artillery Committee's representatives, who believed that the useful work should more properly be referred not to the total weight of the rocket, but only to that of the rocket propellant.[101] Furthermore, it was pointed out that Rudakov's criterion neglected such factors as flight accuracy and the efficiency of the payload (in the case of rocket flares, for instance, the brightness of the illumination).

Unfortunately Rudakov's idea of the comparative evaluation of rockets of differing design received no further attention, and at the period in question no satisfactory criteria for the evaluation of rockets were developed.

From the above it is clear that before World War I no solution was found to the problem of building satisfactorily functioning, reliable rocket flares. Once the war had begun, however, the need for such rockets rose sharply. The Shostka Gunpowder Plant was pressed to quadruple its daily production of flares from 50 to 200 rockets.[102] During 1915 the plant's rocket workshop was greatly expanded, other buildings were fitted out, and a new mechanical plant was installed.

In August 1915 the Chief Artillery Administration informed the Central Committee of War Industries that the army required 10,000 rocket flares per month.[103] The Mechanical Section of the Committee thereupon prepared to place an order for 150,000 rockets (from October 1915 to December 1916). Since the production of rocket casings remained one of the greatest bottlenecks and lagged far behind front-line needs, slowing down rocket production, it was decided to order 50,000 additional casings from the Kiev Arsenal,[104] and a further 8000 from the United Siberian Rolling Mills.[105]

Despite their wide application, the rocket flares produced continued to be of low quality, and this attracted the attention of many commanders of the Army in the Field. In April 1915, for example, Lieutenant-General E. A. Kolyankovskii, Commander of the 15th Army Corps, mentioned the following deficiencies of the rocket flares in current use:

"1) In leaving the stand the rocket trails a strip of fire 15 sagenes [35 yd] in length and about 8 vershok [14 in] in diameter, giving the enemy an accurate indication of the stand's location.

"2) The terrible noise and masses of smoke produced by the launching eases the enemy's orientation and aiming of his ordnance.

"3) Short range.

"4) Inadequate light and brief duration of illumination (about 15 sec)."[106]

Ensign Kucherov of the Household Combat Battalion also discussed the serious defects of rocket flares in a written report on the unsatisfactory methods of illumination being used by the Army in the Field, which he submitted to the Department of Gunpowder and Explosives in October, 1915.[107]

In that year the Artillery Committee, considering the question on methods of illumination, pointed out that despite the familiar defects of rockets listed in Lieutenant-General Kolyankovskii's report, rocket flares were still widely used because of their lightness and mobility, and their simplicity by comparison with other means of illumination, such as searchlights and luminous projectiles.[108]

While rockets were being used for local illumination in Russia, attempts were also being made to apply them for other purposes. The military rockets of Captain Budevskii of the Bulgarian Service were tested in Petersberg in 1913, though without success.[109]

In August of the same year the Admiralty requested the Chief Artillery Administration to give the Shostka Gunpowder Plant an order for 50 3" rescue rockets.[110] In September 1913 this order was increased to 300 rockets, and in January 1914 it was doubled again.[111]

In February 1915 an order for 20,000 3" and 4" rockets of the same type as flares, but without the luminous heads, arrived from the naval battalions of the Army in the Field. These rockets were to be used to bombard wire entanglements with grapnel.[112]

During the First World War many persons and organizations in Russia worked to improve rocket flares. In September 1915 Major-General E. B. Pokhvisnev, in charge of artillery supplies for the northern front, reported to the Chief Artillery Administration that the Fifth Army had tested rocket flares manufactured in Petrograd in the private laboratory of A. P. Serebryakov. The report emphasized that "the results obtained were excellent: simplicity of handling, duration of combustion 1 — 2 minutes, considerable area illuminated."[113]

Also engaged in the creation of new methods of illumination were Major-General Helfreich, Captain Likhonin, Junior Captain Artem'ev, Second Lieutenant Makhonin, the War Industries Committees of Moscow, Kiev, and Khar'kov, the Troitskii Plant, the Vaulin Plant, etc.[114]

In considering their work, however, it must be borne in mind that in these years illuminating projectiles which did not work on a reaction principle were also often termed rockets. In particular, the so-called hand-rockets, which were shot from a special pistol or rifle and were essentially illuminating cartridges, achieved widespread use.

The most important rocket flare designs of this period are those of Junior Captain V. A. Artem'ev and Lieutenant I. I. Makhonin.

Vladimir Andreevich Artem'ev began work on rocket flares before the First World War, when he was stationed at the fortress of Brest-Litovsk. During the years 1915 and 1916 Artem'ev introduced a number of improvements in the design of 3" rocket flares. He proposed to replace the pellets by parachute flares with aluminum powder, which would greatly increase the duration of the illumination, an important criterion in the evaluation of rockets.

At the beginning of 1916, I. I. Makhonin, Second Lieutenant of the Engineers, proposed an "illuminating self-propelled projectile," which consisted of "a rocket turbine with the capability of bombarding the enemy not only with a luminous bomb, but also with explosives, asphyxiating gases, and a smoky compound."[115]

Makhonin's design for his rocket projectile, however, took the form of a simple sketch unaccompanied by numerical data or description. "As far as can be judged," ran the Journal of Section VI of the Artillery Committee, "Second Lieutenant Makhonin's projectile consists of a metal drum filled with certain substances, which must be propelled by five rockets spaced in a circle and resting with their heads upon the drum."[116]

The tests of Makhonin's projectile in March 1916 gave very good results, which led the Field Inspector-General of Artillery to raise the question of manufacturing 500,000 such rockets. "To emphasize the importance of such a device as a rocket turbine-engine," he remarked, "I request that it be given the widest possible use by placing on the turbine some chemical substance, in particular, an explosive, and thus transforming it into an aerial mine, which, when used in concentrated large numbers against a given enemy target, would prove to be a powerful and fearsome weapon."[117]

Repeated experiments performed in July 1916 did not, however, confirm this promise. As noted in the Artillery Committee Journal, "Not one rocket worked properly and fulfilled its function."[118] The results of tests held in September were little better; almost half of the rockets launched refused to function. As a result of these tests the Artillery Committee held that Makhonin's rockets did not fulfill their purpose and were therefore unsuitable for purposes of illumination.[119]

In October 1916 the Headquarters of the Supreme Commander-in-Chief held comparative tests of various illuminating and rescue devices, including rockets.[120] Because of a disagreement between the Artillery Committee and the Office of the Inspector-General of Artillery as to how the results should be interpreted, however, it was decided to repeat the tests in the spring of 1917.[121]

The illuminating devices tested included 3" rocket flares of fortress type, manufactured by the Shostka Gunpowder Plant and converted by

Junior Captain Artem'ev into parachute rockets, and Second Lieutenant Makhonin's rocket missiles.

It was originally planned also to test Ennatskii's 3" rocket flares, but they did not arrive in time and were therefore excluded.

Artem'ev's rockets received praise, but were recognized as suitable only for fortress and shore warfare. Their clumsiness, together with the fact that they revealed the launching point, were awkward to transport when adjusted, and required a special stand, made them unfit for field and trench warfare.[122]

Makhonin's rocket missiles came in for sharp criticism as extremely dangerous in operation and awkward. The common opinion of the delegates from the front was that they were altogether unsuitable as illuminating projectiles, and should be rejected.[123]

No satisfactory design for rocket missiles was thus developed before the end of World War I. This was largely to be explained by the fact that black smoky powder, a relatively low-calorie fuel, continued to be used as the energy source for rockets.

Further improvement of solid propellant rockets required replacement of the relatively weak forced compound by a better and more caloric fuel, and efforts in this direction were begun as early as 1915, when I. P. Grave, an instructor in the Artillery School, proposed the use of a new rocket propellant based on smokeless pyroxylin powder.[124]

The Artillery Committee considered this proposal, and although it met no essential objections, it was rejected because its development would have required a long time, and the war seemed likely to end soon, making it pointless to embark on an extended project.

After this refusal, in 1915 the inventor turned to the board of the Shlissel'burg Gunpowder Plants of the Russian Society for the Manufacture and Sale of Gunpowder, presenting his initial considerations as to the percentage composition of the new powder.

The board conducted a few preliminary experiments, but with unsatisfactory results, and informed Grave that his mixture disintegrated without giving a compact mass. They nonetheless allowed him to work privately in the plant, placing at his disposal the plant laboratory and two assistants.

The first stage of the experiments was concerned with obtaining a compact and only slightly compressed mass by hot rolling a mixture of two sorts of pyroxylin with stabilizing substances. A compact mass was obtained in the form of ribbons or even strips, and cut into pieces which were then fed into a preheated press equipped with a compound matrix. Leaving one upper input opening in the press, Grave obtained the gunpowder mass in the form of a bar 70 mm in diameter, which was then cut by hand into cylindrical pieces. The cylinders were dried briefly, and after 48—72 hours hardened to such an extent as to permit machining on a lathe and drilling of a central longitudinal channel. A liquid solvent was used to seal the drilled-out channel at one end with a thin disk of the same mass.

On 14 July 1916 (certificate No. 746), Grave received a patent for:

"1) A military, or luminous rocket, distinguished by the use, in place of a forced compound, of a compressed cylinder of gelatinized nitrocellulose with an admixture of stabilizing substances.

"2) The method of manufacture of this rocket, which is distinguished by the fact that the cylinder substituted for the forced compound has one or more longitudinal sealed channels."[125]

Replacement of forced rocket compound by smokeless (colloidal) powders was threfore proposed as early as 1916, and experiments on the manufacture of cylinders of compressed nitrocellulose were actually begun. However, neither in 1916 nor later did Grave succeed in arranging experiments on the use of his cylinders in jet missiles. The triumph of smokeless powder over forced rocket propellant thus remained uncertain until the end of World War I.

NOTES

[1] See Otchety o deistviyakh Voennogo ministerstva za 1889—1900 g. (Reports on the Activities of the War Department for 1889—1900). Sankt-Peterburg, 1891—1902.

[2] Ivanov. Spuskanie raket bez upotrebleniya spuska (Rocket Launching without Use of an Incline).— Artilleriiskii Zhurnal, No. 3, Section I, pp. 313—315, 1902.

[3] Alteration in the Design of Signal Rockets. Artillery Committee Journal No. 400.— Artilleriiskii Zhurnal, No. 11, official section, p. 358, 1902.

[4] Artillery Command No. 123, 12 September 1904. — Artilleriiskii Zhurnal, No. 12, official section, p. 260, 1904.

[5] Ibid., p. 261.

[6] Artillery Order No. 95, 1908.— Artilleriiskii Zhurnal, No. 9, Official Section, pp. 76—77, 1908.

[7] Artilleriiskii Zhurnal, No. 6, Official Section, p. 25, 1904.

[8] From the Report of Major-General Belyi, Artillery Commander of the Vladivostok Fort.— AIM Archive, Artillery Committee store, entry 39/3, file 585, sheets 217—219.

[9] The table is compiled from the reports made by the Commanders of Russia's various military regions to the Chief Artillery Administration. TsGVIA, store 504, entry 8, files 1370, 1373, 1376, 1378, 1379, 1382, 1384, 1391, 1392, 1393, 1396.

[10] AIM Archive, Artillery Committee store, entry 39/4, file 417, sheet 320.

[11] Sonkin, M. Russkaya raketnaya artilleriya (Russian Rocket Artillery), Moskva, 1952; Shuvaev, N. A. Istoriko-kriticheskii analiz razvitiya osnov mekhaniki peremennoi massy (A Historico-Critical Analysis of the Development of the Fundamental Mechanics of a Variable Mass). Dissertation.— Gorki State University, 1955; Lyapunov, B. V. Raketa (Rockets). Moskva, 1960.

[12] It should be noted that most of the documents to be found in the archives relating to the research done on solid propellant rockets in Russia during the early years of the 20th century were discovered by V. A. Guseva-Tarasova (Postgraduate, MVTU), and figured largely in her dissertation (1958).

[13] Andreev. Boevye rakety s trubchatym khvostom (Military Rockets with Tubular Tails). — AIM Archive, Artillery Committee store, entry 39/3, file 246, sheets 245—248.

[14] AIM Archive, Artillery Committee store, entry 39/3, file 246, sheet 246.

[15] Ibid., sheet 247.

[16] Artillery Committee Journal, No. 630, 1 November 1891. — AIM Archive, Artillery Committee store, entry 39/3, file 246, sheet 240.

[17] AIM Archive, Artillery Committee store, entry 39/3, file 246, sheet 248 obverse.

[18] Ibid., sheet 247.

[19] Ibid.

[20] Ibid., sheets 251—251 obverse.

[21] Artillery Committee Journal, No. 400, 24 July 1902. — AIM Archive, Artillery Committee store, entry 39/3, file 349, sheet 299. See also Artilleriiskii Zhurnal, No. 11, Official Section, p. 357, 1902.

[22] AIM Archive, Artillery Committee store, entry 39/3, file 349, sheet 275.

[23] Pomortsev, M. Opyty po primeneniyu raznoi formy poverkhnostei k dvizhushchimsya raketam (Experiments on the Application of Surfaces of Various Shapes to Moving Rockets). — AIM Archive, Artillery Committee store, entry 39/3, file 349, sheet 372.

[24] AIM Archive, Artillery Committee store, entry 39/3, file 349, sheet 376.

[25] Ibid.

[26] Ibid., sheets 373 obverse — 374.

[27] Pomortsev, loc. cit., sheets 373 obverse—375.

[28] Ibid., sheet 375.

[29] AIM Archive, Artillery Committee store, entry 39/4, file 417, sheet 295.

[30] Artillery Committee Journal, No. 62, 27 January 1906. — TsGVIA, store 504, entry 8, file 1445, sheet 18.

[31] Ibid., sheets 18—18 obverse.

[32] TsGVIA, store 504, entry 8, file 1445, sheet 20.

[33] For a description of the experiments see the Artillery Committee Journal, No. 357, 5 April 1908. — AIM Archive, Artillery Committee store, entry 39/3, file 585, sheets 45—54.

[34] Pomortsev, M. Rezul'taty opytov s raketami novogo tipa, proizvedennykh v 1907 godu v g. Nikolaeve i Ochakove (Results of Experiments with Rockets of a New Type, Performed in 1907 at Nikolaev and Ochakov). — AIM Archive, Artillery Committee store, entry 39/3, file 585, sheets 50/71 — 50/71 obverse.

[35] Artillery Order No. 123, 1904, and Chief Artillery Administration Circular No. 47, 1905.

[36] These experiments are described in S. V. Karabchevskii's report of 12 May 1909. AIM Archive, Artillery Committee sotre, entry 39/3, file 585, sheets 277 obverse — 279.

[37] Ibid., sheet 279.

[38] AIM Archive, Artillery Committee store, entry 39/3, file 585, sheets 404 — 405.

[39] AIM Archive, Artillery Committee store, entry 39/3, file 349, sheet 408.

[40] Ibid., sheets 408 — 408 obverse.

[41] Ibid., sheet 408 obverse.

[42] Pomortsev, M. Proekt ustroistva rakety so szhatym vozdukhom (Design for a Compressed-Air Rocket). — AIM Archive, Artillery Committee store, entry 39/4, file 417, sheets 299 — 302.

[43] AIM Archive, Artillery Committee store, entry 39/4, file 417, sheet 301.

[44] Artillery Committee Journal, No. 42, 18 January 1906. — AIM Archive, Artillery Committee store, entry 39/4, file 417, sheet 307.

[45] Artillery Committee Journal, No. 497, 30 May 1907. — Ibid., sheet 434.

[46] Artillery Committee Journal, No. 357, 5 April 1908. — AIM Archive, Artillery Committee store, entry 39/3, file 585, sheet 52.

[47] Ibid., sheets 53 obverse — 54.

[48] AIM Archive, Artillery Committee store, entry 39/3, file 585, sheets 54 — 54 obverse.

[49] Ibid., sheets 406 — 417.

[50] Ibid., sheet 279 obverse.

[51] AIM Archive, Artillery Committee store, entry 39/3, file 585, sheets 267 obverse — 268.

[52] Artillery Committee Journal, No. 86, 27 January 1910. — AIM Archive, Artillery Committee store, entry 39/3, file 585, sheet 434 obverse.

[53] Ibid., sheet 436.

[54] AIM Archive, Artillery Committee store, entry 39/3, file 585, sheet 283.

[55] Tekhnika vozdukhoplavaniya, No. 1, p. 9, 1912.

[56] The contents of Ryabushinskii's article are described in the book: Rynin, N. A. Rakety i dvigateli pryamoi reaktsii (Rockets and Ramjet Engines). Leningrad, 1929.

57 Excerpted from the Artillery Committee Journal, No. 277, 1909.— AIM Archive, Artillery Committee store, entry 39/3, file 704, sheet 243.

58 Gerasimov, N. Zhiroskopicheskaya raketa (A Gyroscopic Rocket).— AIM Archive, Artillery Committee store, entry 39/3, file 577, sheet 14.

59 Ibid.

60 For a description of the rocket's mechanism, see Ibid., sheets 19—21.

61 Gerasimov, N. Zhiroskopicheskaya raketa.—AIM Archive, Artillery Committee store, entry 39/3, file 577, sheet 21.

62 Ibid., sheet 14 obverse.

63 Ibid., sheet 15 obverse.

64 Ibid.

65 Journal of the Special Conference of 1 and 11 September 1909.— AIM Archive, Artillery Committee store, entry 39/3, file 577, sheet 44 obverse.

66 Ibid., sheets 44 obverse—45.

67 From Military Engineer Gerasimov's report.— AIM Archive, Artillery Committee store, entry 39/3, file 577, sheet 138.

68 Ibid., sheets 140—140 obverse.

69 Journal of the Committee's session of 3 July 1912.— AIM Archive, Artillery Committee store, entry 39/3, file 577, sheet 348 obverse.

70 AIM Archive, Artillery Committee store, entry 39/3, file 585, sheet 441.

71 Ibid., sheet 442.

72 Ibid.

73 Report of I.V. Volovskii, 19 April 1912.— AIM Archive, Artillery Committee store, entry 39/3, file 704, sheets 203—207.

74 Artillery Committee Journal, No. 629, 3 June 1912.— AIM Archive, Artillery Committee store, entry 39/3, file 704, sheets 199—201.

75 AIM Archive, Artillery Committee store, entry 39/3, file 704, sheet 212.

76 Description of the rocket of improved type No. II and No. III (patent No. 52725).— AIM Archive, Artillery Committee store, entry 39/3, file 704, sheets 244, 245.

77 Artillery Committee Journal, No. 1254, 3 December 1912.— AIM Archive, Artillery Committee store, entry 39/3, file 704, sheets 241—243.

78 For a description of the design of the rocket battery and rocket mitrailleuse see AIM Archive, Artillery Committee store, entry 39/3, file 704, sheets 251—252.

[79] Memorandum No. 464 of the Inspector of Gunpowder and Rocket Plants, 31 December 1905. TsGVIA, store 504, entry 8, file 1375, sheet 3.

[80] Ibid., sheet 43.

[81] Excerpt from the War Council Journal, 20 November 1909. Ibid., sheet 137.

[82] On this see TsGVIA, store 504, entry 8, file 1375, sheet 604.

[83] AIM Archive, Artillery Committee store, entry 39/4, file 417, sheet 185.

[84] Ibid., sheet 188.

[85] AIM Archive, Artillery Committee store, entry 39/4, file 417, sheet 188 obverse.

[86] TsGVIA, store 504, entry 8, file 1445, sheets 246 obverse—247.

[87] Ibid., file 1473, sheet 10 obverse.

[88] TsGVIA, store 504, entry 8, file 1445, sheets 245 obverse—248.

[89] Ibid., sheet 244 obverse.

[90] Ibid., sheet 253.

[91] Report on testing of Major-General Sazanov's rockets. TsGVIA, store 504, entry 8, file 1473, sheet 11.

[92] Ibid., sheet 12.

[93] Copy of Artillery Committee Notice, 18 June 1914. Ibid., sheet 4.

[94] From Junior Captain Ennatskii's report. AIM Archive, Artillery Committee store, entry 39/3, file 585, sheet 50/48.

[95] Report of Guards Captain Ennatskii.— AIM Archive, Artillery Committee store, entry 39/3, file 585, sheets 143—147.

[96] Artillery Committee Journal, No. 83, 24 January 1909.— AIM Archive, Artillery Committee store, entry 39/3, file 585, sheet 148 obverse.

[97] TsGVIA, store 504, entry 8, file 1445, sheet 266.

[98] Ennatskii's Report.— AIM Archive, Artillery Committee store, entry 39/3, file 704, sheets 126—133.

[99] TsGVIA, store 504, entry 11, file 331, sheet 2.

[100] TsGVIA, store 504, entry 8, file 1473, sheet 13.

[101] Ibid., sheet 12.

[102] TsGVIA, store 504, entry 8, file 1395, sheets 3, 26, 52.

[103] TsGVIA, store 504, entry 11, file 314, sheets 6, 7.

[104] TsGVIA, store 504, entry 8, file 1395, sheet 10.

[105] Ibid., sheets 5—6.

[106] TsGVIA, store 504, entry 8, file 1395, sheet 13.

[107] Ibid., file 1396, sheets 1—2.

[108] Artillery Committee Journal, Section II, No. 1229, 27 July 1915. TsGVIA, store 504, entry 8, file 1395, sheet 158.

[109] AIM Archive, Artillery Committee store, entry 39/3, file 795, sheets 15—19, 88—89, 92—100, 108—110, 114—115.

[110] TsGVIA, store 504, entry 8, file 1390, sheet 1.

[111] Ibid., sheets 3, 20.

[112] Ibid., file 1395, sheet 1.

[113] TsGVIA, store 504, entry 11, file 316, sheet 1.

[114] For more details of these rockets, see the papers of Section VI of the Artillery Committee. TsGVIA, store 504, entry 7, file 687, and also entry 11, files 314, 324, 326, 330, 332, and 345.

[115] TsGVIA, store 504, entry 11, file 321, sheet 29.

[116] Ibid., sheet 40.

[117] Ibid., sheet 29 obverse.

[118] Journal of Section VI of the Artillery Committee, No. 2980, 31 July 1916.-TsGVIA, store 504, entry 11, file 321, sheet 83.

[119] Journal of Section VI of the Artillery Committee, No. 3759, 27 September 1916; Ibid., sheet 104 obverse.

[120] TsGVIA, store 504, entry 11, file 321, sheets 113—116.

[121] TsGVIA, store 506, entry 2, file 370, sheets 1—10.

[122] TsGVIA, store 506, entry 2, file 370, sheet 6.

[123] Ibid., sheet 6 obverse.

[124] The information on Grave's work is taken primarily from the article of Serebryakov, M. E. Ob otechestvennom prioritete v oblasti artillerii (Russian Pre-eminence in Artillery). — Izvestiya Voennoi artilleriiskoi inzhenernoi akademii imeni Dzerzhinskogo, Vol. 91, pp. 25—29. Moskva, 1955.

[125] Serebryakov, M. E. op. cit., p. 26.

CONCLUSION

Over a considerable stretch of time — from the end of the 18th century to the Great October Revolution — Russian designers and researchers contributed a great deal to the improvement of solid propellant rockets. However, Russian rocketry did not follow a smooth, even path of evolutionary development. During its 250 years of history a rise and fall of interest in various types of rockets, and periods characterized by sharp criticism of rocket weapons occurred more than once.

Despite the repeated attempts of scientific historians to ascribe the beginnings of rockets in Russia to the 14th, 12th, and even 10th centuries, their assumptions cannot be substantiated either analytically or by documents, and must be regarded as highly unreliable. Documents indicate that rockets were first used in Russia during the second half of the 17th century.

At first they were used only to create fireworks and illuminations for entertainment. Only during the first quarter of the 18th century did the army come to adopt them as a means of giving signals.

Pyrotechnic rockets came into widespread use in Russia at the turn of the 18th century, thanks mainly to the activity of Peter I. During his reign new fireworks laboratories were built, a number of foreign works on artillery and pyrotechnics were translated into Russian, national cadres of pyrotechnic experts began to be formed, and signal rockets were first used by the army.

During the period dealt with in this book solid propellant rockets underwent significant changes. The rockets of the 17th and 18th centuries were quite primitive from an engineering point of view, and their production depended to a great extent on the experience and skill of the masters. They consisted of a cardboard casing containing a payload (pyrotechnic compounds) and a rocket chamber, which served simultaneously as reservoir for the rocket propellant and combustion chamber. To stabilize the rockets a long wooden bar (the tail), which absorbed the pressure of the countercurrent of air and maintained a certain position of the longitudinal axis, was attached to the casing.

The rocket experts of this period devoted particular attention to the composition of the rocket mixture, since they believed the quality of pyrotechnic rockets to depend primarily on its correct choice. A great many formulas, all basically consisting of nitrates, sulfur, and carbon, taken in different proportions, were worked out — all empirically.

The idea that choice of the design parameters, as well as of the rocket mixture, affected the quality of rockets became established only at the end of the 18th century, and it was reflected in the works on artillery and pyrotechnics published at that period.

By the beginning of the 19th century Russian pyrotechnicians had accumulated a good deal of experience in the production and use of

pyrotechnic rockets. Efficient ratios and dimensions for the rocket casing and tail had been worked out, composition of the rocket mixture had been determined and its fill density regulated, and the significance of the dimensions and shape of the ignition channel were understood. The books on the art of pyrotechnics published early in the 19th century even included descriptions of multistage and composite rockets (rocket clusters).

All of the results obtained, however, were obtained empirically and were based not on theoretical, but on exclusively experimental considerations. By the beginning of the 19th century there was still no theory of explosive compounds, rocket design, or rocket flight.

This was to be explained to a large extent by the fact that up to the end of the 18th century, in Russia as in other European countries, rockets were used exclusively for fireworks displays and to give signals at night. As a result the demands made upon them were not very great and were satisfied by the numerous experiments of the pyrotechnicians, without any great need for a fundamental theory of rocketry being felt.

At the end of the 18th century in India, however, and after the turn of the 19th century in Europe rockets again acquired military significance, and in Russia the question of producing military rockets arose, to occupy the Military Study Committee for a number of years. The first successful Russian designs for military rockets were produced by Kartmazov and Zasyadko, working independently, in the years 1814—1817, but achieved no widespread success.

The principal difference between the military rockets of the first quarter of the 19th century and the pyrotechnic rockets was in the composition of the payload and the material from which the casings were fabricated (cardboard was replaced by metal). Furthermore, while in pyrotechnic rockets the pyrotechnic compound and the rocket mixture were both enclosed in the casing and constituted a whole from the manufacturing point of view, the military rockets of the beginning of the 19th century were characterized by a clear division between the rocket casing and the warhead. They were separate parts, manufactured separately, and joined only when the rocket was finally assembled.

A practical solution to the problem of mass production of military rockets in Russia and their introduction to regular use in the army was found only during the second half of the 1820's. The first experiment in the massed use of military rockets occurred during the Russo-Turkish War of 1828—1829, when the Russian troops made relatively great use of rockets at Shumla and at the sieges of Varna and Silistria.

This military experience showed the great potential of rocket weapons, while it also demonstrated the poor quality of those then actually in use. The rockets of the 1830's and 1840's suffered from a number of serious defects, including relatively short range, inaccuracy, and worst of all, unreliability in operation.

These years saw the use of signal, incendiary, and military rockets supplemented by attempts to use rockets for the destruction of fortifications, local illumination, and submarine armament. Experiments undertaken for these purposes failed to yield positive results.

Until the middle of the 1840's Russian rocket engineering developed very slowly, and the poor quality of rockets impeded their widespread use. Many of the corps of army commanders took a dim view of rocket weapons and sought to prevent them from reaching the troops. During the forties,

however, this situation changed radically. The development of military activity in the Caucasus resulted in a sharp upswing of demand for military rockets. Such advantages of rockets as their lightness, adaptability to firing without heavy ordnance, and ready application in massed salvoes clearly appeared during battles in mountainous terrain difficult of access. Although military rockets could not compete with artillery in range and accuracy, they proved a very successful complement to it.

The steep increase in the production of military rockets made the question of their quality even more pressing, and it became essential to improve their range and accuracy of firing, and even more, to make them safe to use.

Rocket weapons achieved their most widespread use, in Russia as in most other European countries, about the middle of the 19th century, when military rockets were being produced in very great numbers and sent to almost all military regions. They were often used in military actions, and in a number of instances special rocket battalions performed with success. Sea-going ships began to be armed with military rockets.

A great deal of work was done to improve the design and manufacturing techniques of military rockets. During this period the PRZ group was ably headed by K. I. Konstantinov, one of the greatest exponents of the mid-19th century Russian artillery school, whose contribution to the development of Russian rocketry was enormous.

As already noted, Konstantinov was one of the world's greatest experts on rocket production, had a thorough knowledge of the history of rocketry and carefully followed the most recent developments in foreign countries such as Austria, England, Prussia, and France, in order to make use of all the advantages they presented. Konstantinov's work also was widely known outside Russia and influenced the development of rocketry throughout the world.

Konstantinov introduced a number of significant improvements in the design and manufacture of military rockets. Under his direction the Petersburg Rocket Institute was almost completely re-equipped. He also proposed a whole series of measures designed to improve the quality of military rockets and make their production safe.

The adoption of these measures did bring about some improvement in the quality of Russian military rockets, with increases in range, accuracy, and life in storage, while cases of premature explosion were almost entirely eliminated. However, no fundamental improvement in the quality of rockets was attained at PRZ. As previously noted, the disparity between the number and extent of Konstantinov's projects and those actually realized is striking.

By the end of the 1850's the reorganization of the Petersburg Rocket Institute was basically complete and such possibilities for the improvement of military rockets as existed in the Institute itself had been almost fully exploited. Nonetheless, despite all the improvements introduced during the preceding decade, the engineering plant of the Institute remained very poor.

Konstantinov's biggest project — the replacement of manual labor by mechanized production — was not accomplished at PRZ, where most operations continued to be performed manually. As before a mechanical motor, of any sort whatsoever, was unavailable, and all the machines

were actuated by sheer muscle power, which involved a considerable number of men. Further improvement in military rockets was impossible without fundamental change in manufacturing techniques. The primitive production techniques, in which manual labor was predominant, had to be abandoned in favor of automation, with all major processes performed by machine. Konstantinov sought to bring this about by designing a new rocket institute at Nikolaev and ordering the necessary plant for it abroad. However, the construction of the Nikolaev Rocket Institute was repeatedly interrupted and was not completed before the beginning of the 1870's.

In addition to military rockets, pyrotechnic and signal rockets were still being produced in Russia at this period. During the second half of the 19th century rockets also came to be used for illumination and for throwing rescue lines to ships in distress. The same period saw the first attempts to use rockets as aircraft engines.

The development of Russian rocketry up to the middle of the 19th century was characterized by the absence of any theoretical principles of rocket design and production. The accumulation of experimental data, without any attempt at serious scientific analysis of the factors governing the performance and quality of rockets, was considered sufficient. The improvements made in the design of military rockets were generally based neither on theoretical nor experimental research, but rather on the intuition and guesswork of individuals. Konstantinov was the first to undertake a scientific approach to the problems of rocket design, and he laid the foundations of experimental rocket dynamics.

His empahsis on experimental research was deliberate, for while Konstantinov did not deny the need for "a mathematical theory of rocket design and firing," he regarded experimentation as the principal means for improvement of rockets.

This choice was also to be explained by the complexity of the processes occurring inside a rocket, which were difficult to analyze. At the middle of the 19th century science possessed no methods for the precise determination of such factors as the temperature of the gases, their pressure, taking into account the continuous flow, the exhaust velocity of the combustion products, etc.

Experimentation was therefore the simplest and most natural method. During the 1840's and 1850's PRZ conducted a great many experiments to determine the significance of the composition and fill density of the rocket mixture, dimensions and shape of the ignition channel, number and cross-sectional area of the exhaust orifices, etc.

By the end of the 1850's the researchers had quite a good idea of the qualitative interrelationship of these factors. Konstantinov tried to use his extensive experimental data to determine the optimum parameters of military rockets, but was impeded in his attempt by the unsatisfactory experimental basis, and the lack of precise measuring instruments, which made it impossible to determine exact numerical relationships.

Konstantinov died in 1871. The vast body of experimental data gathered at PRZ had no great scientific reverberations, and a theory of rocket motion was not born before the end of the 19th century.

At the beginning of the seventies, when the Nikolaev Rocket Plant went into operation, it was already quite clear that rockets running on black smoky powder could compete with artillery pieces neither in range nor in

firing accuracy. The development in artillery engineering which resulted from the successes of metallurgy, chemistry and ballistics (steel casting, rifled barrels, and smokeless powder), made rockets worthless as weapons and the last third of the 19th century saw their retirement in Russia, just as in the other countries of Europe.

This step marked the end of an era in the development of Russian rocketry. Encompassing more than sixty years, this period saw the rise, comparatively widespread dissemination, and rapid fall of rocket weapons, and left a notable trace in the history of Russian military engineering.

It was also of great importance in the development of Russian rocket theory and engineering, since it saw the foundations of the design of solid propellant rockets laid, the first attempts at the creation of the new science of experimental rocket dynamics, and the expression of a number of ideas which would influence the course of research in rocketry for many years.

During the second half of the 19th century, repeated attempts were made in Russia to power aircraft by means of gunpowder rockets. Several original designs for solid propellant rocket engines, both for lighter-than-air and heavier-than-air craft, were proposed.

Inventors were attracted by the apparent simplicity of using jet engines to achieve flight. However, most of them did no more than present the plan of an engine, unaccompanied by the details of its construction or of the precise amount of energy required for jet flight. Not one of these designs was actualized during the period under consideration.

Even later, however, solid propellant rocket engines were not used as independent aeroengines, because of their very brief operating time (governed by the combustion time of gunpowder) and the difficulty involved in regulating their thrust.

The retirement of military rockets did not, however, signify the termination of all rocket production. Signal rockets, rescue rockets, and pyrotechnic rockets continued to be produced in Russia into the 20th century. The so-called luminous rockets achieved particularly widespread use during this period in fortresses and siege-trains, and constituted an integral part of the Russian army's means of illumination.

However, despite their widespread use, rocket flares were still of poor quality. At the beginning of the 20th century a number of researchers sought to improve them, in particular, by increasing their range and accuracy, and by prolonging the duration of the illumination. Some encouraging results were obtained, but fully satisfactory rockets were not developed before the end of World War I.

Repeated efforts were made to revive military rockets in spite of their retirement. These efforts were redoubled in the years immediately preceding World War I. The successes in the development of aeronautics and aviation gave every basis for assuming that the airforce would play a significant role in the next war. Efforts were therefore made to create a new type of anti-aircraft rocket, concurrently with work on rockets for field warfare.

Examination of the experiments conducted by Russian researchers at the beginning of the 20th century shows that they were confronted by essentially the same basic problems faced by their predecessors in the middle of the preceding century: increase of range, and close grouping of rocket fire.

However, the intervening progress in the various branches of engineering made possible a much more satisfactory resolution of long-standing problems. At the beginning of the 20th century rocket engineering was able to profit from seamless steel casings and improved measuring apparatus.

The means for stabilizing rockets were also improved. Most designs at the beginning of the 20th century rejected the wooden tail in favor of superior devices, such as stabilizing surfaces, or a gyroscope.

The level of scientific knowledge among rocket engineers at this period was still low. Most of the Russians engaged in the construction of new types of solid propellant rockets were not acquainted with the theoretical papers on jet propulsion, and in some cases entertained naive and downright erroneous ideas as to the origin and character of reactive force. The researchers also made no effort at a theoretical solution of such problems as the determination of the velocity and range of a rocket, and displayed total lack of interest in such ideas as the efficiency of a rocket engine or of the rocket as a whole.

The fundamental drawback of all rocket designs at the beginning of the 20th century remained the use of such a relatively low-calory fuel as black smoky powder. This delayed progress in rocketry and resulted in the fact that from a tactical and engineering point of view the specifications of most rockets at the turn of the 20th century differed only slightly from those of the rockets of 50 years before, designed by Konstantinov (they were still characterized by relatively low range, considerable deviation, and premature explosion).

Before the end of World War I no military rockets that could sustain comparison with rifled artillery were built. There was a corresponding lack of satisfactorily functioning rocket flares.

The further improvement of solid propellant rockets demanded the replacement of black smoky powder by better propellants of higher calorific value, based on smokeless powder. This too, however, was achieved only after the end of World War I, when a new stage in the development of solid propellant rockets began.

APPENDICES

1. DESCRIPTION OF THE FIREWORKS OF 1686*

On the 20th day of January in the present 194th year [sic], by decree of the great Tsar Peter Alekseevich, Mighty Prince and Absolute Sovereign of All Greater and Lesser and White Russia, the Russian explosives master Grigorii Prokof'ev and his assistants were ordered to create an entertainment by the shooting of fireworks.

The town had 8 towers, and 100 ascending 2-ounce rockets on each tower.

Twelve quarter-pound high-flying rockets were arranged about each of these towers.

In the cantonment were 4 high-angle cannon, to shoot wooden balls, each containing 100 ground rockets.

There were 10 marquees, each containing 80 2-ounce rockets.

Item, a semicircle containing 35 quarter-pound rockets.

Item, a wooden tub of water, 3 arshin wide; in this tub, a cover and four wooden balls, containing 250 2-ounce rockets.

Item, an octagonal wheel, with 8 1/2-pound rockets.

Item, a cluster of 50 2-ounce rockets.

About this, 8 small tents, each containing 30 2-ounce rockets.

Item, on the ground, a catherine wheel with 250 2-ounce rockets.

Item, on the walls ringing the entire town, 120 rockets, pounders, 1/2-pounders, 1/4-pounders, and 2-ounce rockets.

Item, for the firing entertainment itself: 2 lances, 2 poles, 2 sabers, 2 earthenware pots, 2 cudgels, 6 ropes, 2 kites, 200 ground rockets, 50 1/4-pound rockets.

Item, supplies for the entertainment: 10 pud of hand-cream, 1 1/2 pud refined saltpeter, 1/2 pud sulfur, 10 pounds oil, 50 arshin medium canvas, 30 sheets white iron, a pound of flour, a pud of black tar, 2 pud standard thick ropes, a 150-sagene rope for flying ropes and kites, a pud of rolled iron, 20 pud steel, 1 pud lead, a steel rasp, 2 saws, as many nails of various types as required, 3 good axes, 5 wooden candlesticks, 50 1 1/2-sagene bars of firewood, chopped into 5-vershok sections.

Item, of such things as are not normally found in the treasuries of mighty lords, it was necessary to buy: 5 pounds camphor, 10 pounds turpentine, 5 pounds wire, 5 quires artists' paper, a ream of paper, 10 arshin shiny colored flax, 5 pounds cotton thread, 7 arshin good colored flax, 7 arshin thin canvas, 10 pounds isinglass, 3 pounds turpentine, 10 pounds beeswax, 1 chetverik wheat flour, 1/2 vedro linseed oil, 3 pounds drying oil, 10 pounds thin rope, 1 pud thick rope, a 150-sagene rope for throwing, 1/2 pud lard, 5 pounds crushed tendons, 10 cowhides, 3 copper

* State Historical Museum, Department of Written Sources, store 440, file 378, sheets 9 — 12.

frying-pans, an iron long-handled ladle, 3 sieves, 3 pairs scissors, a large tub, 200 tallow candles, 20 limewood jambs, 10 maplewood jambs, 2 reams grey paper. All these were bought for the sum of 23 rubles, 26 altyn, and 4 coppers [i. e., 23 rubles, 80 kopecks].

2. ROCKETS*

In military tactics rockets are depended upon for attacks upon fortresses. When the batteries, both cannon and mortars, are all ready for firing, since in launching his major attack the general wishes to deliver a powerful salvo against the fortress, he has the chief battery release a rocket as a signal.

Signal rockets in use range from one- to six-pounders. The rocket takes its caliber from the weight of lead it contains. Here, for example, are the dimensions of a 3-pound rocket. Compasses are used to make the rocket's caliber correspond to the dimensions of 3 pounds of lead, and the rocket's length is made equal to 7 such calibers.

Now the rocket casing must be prepared and rolled. The frame of a paper rocket is termed the casing. After the caliber is chosen, it is divided into 7 equal parts, 5 of which give the thickness of the roller or wood on which the paper for the casing is to be rolled, while the thickness of the casing walls is taken as 1/7 caliber. The good heavy wrapping paper is taken, cut along the sheet and transversely to the rocket casing, and rolled upon a roller, while the protruding ends are pasted together. After rolling sufficiently to give the casing a diameter equal to the caliber, it is taken from the roller, and one end is stretched to form a neck. The ends are then so cut as to make the length of the casing equal to 7 calibers. The ends are dipped into molten glue to ensure that the paper does not turn up during filling, and the casing is then ready.

The entire length of the casing should next be divided into three equal parts, of which two are filled with [rocket] compound, while the third is left for the powder, which is strewn over the slag. The mold in which the rocket is to be filled with the compound is made next: small-caliber molds are generally of wood, while brass ones are cast for large sections. The mold should have the same caliber as the rocket, but need not be so long as the casing; $5^{1}/2$ calibers is an adequate length. There is a base plate with a semicircular cap whose diameter should correspond to that of the internal ignition channel of the rocket. On the cap is an iron rod $3^{1}/2$ calibers in length, and with a thickness at the cap of 1/4 caliber or 1/3 the ignition channel diameter. The rod must be a cone tapering towards its upper end.

Compound for a 3-pound rocket

1st compound		2nd compound	
Nitrates	32	Sulfur	1
Sulfur	6.5	Nitrates	2
Limewood coal	14	Gunpowder pulp	3

* Danilov, M. Nachal'noe znanie teorii i praktiki v artillerii s priobshcheniem gidrostaticheskikh pravil (Elementary Theory and Practice of Artillery with an Appendix on the Laws of Hydrostatics), pp. 72 — 74. Moskva, 1762.

Whichever of these two compounds is desired may be chosen. It should be carefully pulverized in a tray, after which it is to be sieved three times. Next four ramrods of diameters corresponding to that of the ignition channel are required: the first, equal to that of the channel; the second, less; the third, still less; and the fourth, least of all. The ramrods are used to stuff the rocket as follows. Placing the casing in the mold, the compound is poured in one ounce at a time, and each such fill is rammed in by 20 or 25 powerful blows of a wooden beetle. When the compound is level with the rod, it should be stuffed in by a solid ramrod without holes, in order to make a one-caliber layer of solid, or, in laboratory parlance, blind compound above the rod.

A wooden disk, with a hole for ignition of the gunpowder from the rocket compound in its center, is placed above the compound, and above it 5 ounces of powder are poured over the slag. Finally the end is drawn together and tightly tied with cord, above which it is glued, and the rocket is then

A faceted awl of the same length as the rod should then be used to clean out the ignition channel, and after thinning the gunpowder pulp in wine, the rocket should be oiled for ignition. The rocket tail should be equal to 7 1/2 or 8 times the length of the rocket, and its thickness at the rocket should be equal to 1/3 caliber. Once the tail has been attached to the rocket, it should be supported on an awl at a point 3 1/2 calibers away from the rocket, so that the whole, including the tail, will be in a state of equilibrium. This concludes our promised exposition of rocket manufacture.

3. DESCRIPTION OF THE MANUFACTURE OF INCENDIARY AND REBOUNDING ROCKETS OF VARIOUS TYPES, MADE ACCORDING TO THE DIMENSIONS AND RULES OF KARTMAZOV, MEMBER, 5TH CLASS, OF THE MILITARY SCIENTIFIC COMMITTEE*

1. Rockets are divided into two types: high-flying and rebounding.
2. High-flying rockets are again subdivided into two types: incendiary, which are 4" in diameter, and, including the cap filled with incendiary compound, from which they take their name, 41" in length; and explosive, which have the same diameter and are 34" in length, including the powder-charged explosive. Rockets of both these types can be used in the siege of fortresses since, as experiments have shown, they fly up to 1260 sagenes [2940 yd] and fall with such force as to bury their entire length, with part of the tail, in the hardest ground.
3. Rebounding rockets are also divided into two types, of which the first, incendiary rebounding rockets, carrying an incendiary compound and explosive, are 2 1/2" in diameter and 28" in length (including the explosive). They may be used to set fire to marshy regions and similar areas which the enemy might use for an ambush, and may also be used with considerable success against enemy cavalry, since they fly along the ground with fire and noise, inflicting injury upon the enemy when they explode. Their range may be reckoned as up to 1000 sagenes [2330 yd], but they may also be used, as desired, at any distance since their range depends upon the launching angle. The second type, rebounding rockets

* TsGVIA, store 35, entry 4/ 245, code 188, file 65, sheets 96—100.

carrying explosive, are 2" in diameter, with an overall length of about 25", and a range of up to 800 sagenes [1870 yd]; they can be used against cavalry.

4. Incendiary rockets and rebounding rockets of large and small caliber are all filled in the same way, with differences only in the number and force of the packing blows.

5. The first type, large high-flying incendiary rockets, are manufactured as follows: copper soldered cylinders, termed casings, with an interior diameter of 4 inches, are made from sheet iron with a thickness of 0.07 or 0.08 English inches. Soldered to the casings at one end are convex copper disks 0.09 English inches in thickness, with a round central aperture which corresponds to the thickness of the ramrod. The length of the casings should be 30 inches. The casing is glued inside five turns of wrapping paper, then set up on a ramrod, mounted on a pile driver 20½ inches in length, in an anvil block. An oaken mold is then fitted over it, and set up perpendicularly. A five-ounce measure is used to pour into the casing a little silt moistened with water and by means of a ramrod 50 blows are made upon this by a 60-pound wooden ram. After thus constructing the mouth of the rocket, which must give passage to its propulsive force, the casing is stuffed with propellant. This is poured in, using the same measure, and, letting the rocket down onto the aforementioned ramrod, 50 blows are inflicted with the same wooden ram. This procedure is continued until the casing is filled. A channel for ignition of the incendiary from the rocket propellant is made in the silt stuffed in above the propellant, and a cap filled with an incendiary compound is mounted on the filled casing. One end of the cap is cylindrical, with internal diameter equal to the external diameter of the casing, while the other end is conical. These two parts have a total length of 19 inches, divided equally between them. In the cylindrical part are three large round orifices, three inches in diameter, while the cone has three similar, but somewhat smaller orifices, two inches in diameter. Finally, there are three small longitudinal orifices near the pointed tip. Throughout its length the cap has a channel communicating with channels leading to all of the orifices mentioned above. All these channels are fed by trowels. The cap is then fitted over the casing by means of a ribbed strip at its end, and is secured by tarred twine wound around it. This is the procedure followed in the filling of incendiary rockets, regardless of their caliber, which affects only the fill measures, quantities of compound and number of blows, which are dependent on the diameter.

6. The second type of high-flying rockets with shells are filled exactly like the above, except that they are fitted with a gunpowder-charged shell instead of a cap with incendiary compound. The weight of explosive corresponds to the caliber of the rocket, and it is secured to a cruciform brace by means of riveted bands of tin and cords.

7. Rebounding rockets are filled exactly like the above.

8. All types of rockets require tails from 6 to 6½ times the length of the rocket, with an equilibrium point one caliber away from the mouth of the rocket, where it is ignited. The tails of large-caliber rockets are screwed together in the middle by nuts, first, because during a campaign it is more convenient to transport them with the two parts unscrewed; second, because when the rockets see action, they can thus more readily be adjusted to the rockets when aiming; and third, because a long tail, always tending to warp, is better protected from warping when divided into two halves.

Cost estimate for parts of one large 4" incendiary rocket	Cost of parts: rubles	kopecks	Notes
4" casing with cap, made in Sesterbek	—	—	Cost unknown to me
Five sheets of wrapping paper for internal glueing	—	50	
Glue for glueing	—	20	
Rocket propellant (incl. losses incurred in its preparation), and preparation of tincture for it	10	38	
Finished pine tail	—	60	
Wire	—	15	
Nuts for screwing	—	—	Arsenal's requirements unknown
Total . . .	11	83	
Fittings and accessories for cap			
Incendiary compound	6	15	
Trowel	—	20	
Resinous cement	—	20	
Resinated flax to cover holes . . .	—	25	
Oilcloth to protect cap from dryness of the air	—	70	
Cords to secure cap	—	40	
Total. . . .	7	90	
Grand total .	19	73	
This rocket, when filled, with cap and tail, *weighs as much as 41 pounds*			

Estimate for a high-flying 4" rocket with shell	rubles	kopecks	Notes
Casing made in Sesterbek	—	—	Cost in Sesterbek unknown
Paper for internal glueing	—	50	
Glue	—	20	
Rocket propellant including tincture	10	38	
Tail	—	60	
Wire	—	15	
Nuts for tail	—	—	Arsenal's requirements unknown
Total . . .	11	83	
Seven pound shell	1	5	
Powder used inside	—	64	
Skirts about shell to secure it to the casing	—	30	
Cords	—	40	
Resinous cement	—	20	
Trowel	—	5	
Resinated flax to cover holes . . .	—	20	
Total. . . .	2	84	
Grand total .	14	67	

For 2.5" rebounding incendiary rockets	rubles	kopecks	Notes
Casing made in Sesterbek	—	—	Cost in Sesterbek unknown
Paper for glueing	—	30	
Glue	—	15	
Rocket propellant	3	2	
Tinctures	—	35	
Tail	—	40	
Three pound shell	—	45	
Gunpowder	—	34	
Cords	—	20	
Skirts about shell to secure it to the casing	—	25	
Resinous cement	—	20	
Trowel	—	5	
Resinated flax to cover holes . . .	—	12	
Total . . .	5	83	

4. ON INCENDIARY AND REBOUNDING ROCKETS*

1. Incendiary rocket casings. The caliber of a large rocket is 4 English inches. The length of the casing is 7 calibers, or 28 inches, while the thickness of its walls is 0.05 inch. The base plate is 0.1 inch in thickness.

Wrapping paper 0.025" thick is pasted onto the sides of the casing at its middle. The orifice in the bottom is 1.5" in diameter. Of the rings securing the tail, the center of the first is located 1.3" from the bottom of the casing, and that of the second is midway between this one and the third, whose center is 14" from the bottom of the casing. The rings are 1.6" in width, while the height of the shackles into which the tail is inserted is 2.05" above the side of the casing.

The caliber of a small rocket is 2.5", while its casing measures 7 calibers, or 17.5", in length. The thickness of the casing walls is 0.05", while that of the base plate is 0.1". Wrapping paper 0.025" thick is pasted onto the sides of the casing at its middle. The orifice in the bottom is 1" in diameter. There are two rings securing the tail, the center of the first of which is 0.6" from the bottom of the casing, while the second is located at the middle of the casing. The width of the rings is 1.2". The height of the shackles into which the tail is inserted is 1.55" above the side of the casing.

2. The cap. The cylindrical part of the cap is 9.2", while the external side of the cone measures 10". The cylinder has 15 longitudinal slits, made for the greatest convenience in assembly and attachment to the casing, which are 4.5" from the head of the cone, and four holes, corresponding to four similar holes 0.9" in diameter in the rocket, 1.3" from the base of the cone. A small cap is made proportional to a large one, according to the ratio of calibers. The holes in the cone of a large cap are arranged as follows: the centers of the first four holes, which are 0.9" in diameter, are 1.5" from the base of the cone, while the next group of three holes, 0.6" in diameter, are 1.5" beyond the periphery of the first set; the third group of two holes, removed a further 1.5", are 0.5" in diameter, while the fourth group of two holes, a distance of 1.5" beyond the third, are 0.25" in diameter. The holes are arranged pyramidally on the cone.

* TsGVA, store 35, entry 4/245, code 188, file 65, sheets 41-47 obverse.

A small cap has three holes in the cylinder, corresponding to three in the rocket, and in the cone a lower row of three, and a second row of two.

3. The axis pole. The length of the pole is five calibers, or 20", while its thickness ranges from 1.5" at its base to 0.6" at its tip. Its base is made in the form of a quadrilateral bolt terminating in a screw with a nut used to secure it to the bar. The length of this bolt, excluding the screw, is from 7" to 9". The length of a small pole is 12.5", and its thickness ranges from 1" at its base to 0.3" at its tip. In other respects it is like the large pole.

4. The ramrods. These are generally turned of the driest and strongest wood, with diameter corresponding to the ignition channel with extremely small tolerance, and length corresponding to that of the casing. The head above this part is turned a little thicker, and has a hole. Ramrods for large rockets are turned in 8's, and for small rockets, in 6's, one smaller than the next by 1/8 part, and in small ones, by 1/6 part, of the rod. Seven of the ramrods are straight-through and the eighth is blind, but in order to pass through them the appropriate measure in accord with their size, the rod is divided into seven equal parts and the first large ramrod is straight-through for the entire length of the rod, while the second passes 6/7 of the length of the rod, the third, 5/7, the fourth, 4/7, the fifth, 3/7, the sixth 2/7, the seventh 1/7 of the length of the rod, while the eighth is blind. For small ramrods, the rod is divided into five parts, and the same procedure is followed. It is most important that the ramrods be truly and properly drilled out in accord with the thickness of the rod, and that they be machined with such small tolerances that they turn freely only during filling, and are easily withdrawn thereafter.

5. The pile driver used for rocket stuffing. The pile driver can be made of any kind of wood, whichever is cheapest, and consists of two bars at least 3 vershok [5 1/4"] thick, at least four vershok [7"] wide, and 3 3/4 arshin [105"] long. They are bound together, 8 vershok [14"] apart, by two cross-beams of the same thickness, though they may be narrower, and 1 sagene [84"] in length. Uprights 3 vershok [5 1/4"] thick, 3 1/2 vershok [6 1/8"] wide, and 5 1/4 arshin [147"] high are then rammed in at a distance of 8 vershok [14"] from the cross-beam. Above they are bound together by a drilled-through beam of the same thickness and width, 14 vershok [24 1/2"] in length. Two beams of the same thickness and width as these uprights, and 8 vershok [14"] in length, are seated by the uprights upon two straight-through tenons, and an iron bolt, over which is fitted a pulley-block, is passed through them. To each upright are nailed two thin beams, forming grooves 2 vershok [3 1/2"] apart, in which a 1 1/2-pud [54-lb] ram must move. Beneath this piledriver a beam at least 3 vershok [5 1/4"] thick and at least 5 1/2 arshin [15"] long is dug into the ground. To this, near its center, is attached the ramrod on which the rocket is filled.

6. The mold. The mold in which the casing is enclosed for filling with propellant is made from the two halves of a log of dry wood, sawn apart longitudinally. The halves are 13 vershok [22 3/4"] long, and 7 to 8 vershok [12 1/4" to 14"] in diameter. Each half is hollowed out into a semicylindrical channel along its entire length, so as to receive half of the casing. The casing is intended to fit compactly when the two halves are closed together over it, and for this purpose they are tightened by an iron band.

7. The propellant used in rockets. This propellant consists of nitrates, sulfur, and carbon.

Proportion for big rockets

Nitrates	18 parts
Sulfur	5 "
Carbon	8 "

Proportion for small rockets

Nitrates	18 parts
Sulfur	3 1/5 "
Carbon	5 4/5 "

To make the propellant, the nitrate, sulfur, and carbon must separately be rubbed and sifted extremely fine, then thoroughly mixed and again sifted several times, since the more finely the compound is rubbed, the better it will perform. A 4" rocket requires 12 pounds 88 zolotniki [12.92 Russian pounds] of this propellant, and a 2 1/2" rocket, 3 pounds 22 zolotniki [3.23 Russian pounds]. The amount of incendiary compound required for a big rocket is 5 pounds 24 zolotniki [5.25 Russian pounds], and for a small rocket, 1 pound 72 zolotniki [1.75 Russian pounds].

8. Regulations for filling with rocket propellant. The casing is so set up and viewed on the pole that it reaches right down to the beam on which the pole stands. Three or four felt disks are then fitted over the pole, which is smeared with fresh pig fat, and the casing is again fitted over the pole and covered with the mold, over which is forced the iron band. Wedges are then driven in at both ends, and the whole is bound about the piledriver uprights with cord. A large ramrod is then inserted into the casing, and a distance of 1 1/2 arshin [42"] from its head is measured upwards along the upright. At this point a hole is drilled in the left upright, and into it is inserted a wooden peg to hold back the ram, so that the operators will not have to hold it in their hands when they pour in the propellant. In order to raise the ram a fixed distance in stuffing, it is raised to this peg, while above, the piledriver uprights are bound with cord, and notches are then made on the ramrod. In stuffing, these marks will show how much propellant should be stuffed in by which ramrod. They are cut as follows: first a trial is made with the first ramrod, lowering it to the very bottom of the casing and, if it is longer than desired, making a notch on it level with the brim of the casing. The second is then lowered, and if it also proves too long, a similar mark is made. This mark is then held level with the lower end of the first ramrod, while the latter is marked at the point reached by the end of the second ramrod. This mark will then indicate how much propellant should be stuffed into the first ramrod. The third ramrod is then lowered into the casing, and should its head also protrude, a notch is made, to be held level with the lower end of the second ramrod. The notch then made on the latter at the point reached by the end of the third ramrod will indicate how much propellant should be stuffed in by the second ramrod and the same method is followed with all the others. It should be noted that when a ramrod is lowered into the casing and the clearance is great, another layer of wrapping paper is pasted onto the casing, to permit the ramrod to turn freely inside it and to allow it to dry;

after lowering the blind ramrod into the casing, however, it is marked level with its brim, and from this mark it is displaced downward 1 1/4 calibers and marked again.

When all this has been done, the stuffing takes place as follows: the propellant is poured into the casing in measures of 24 zolotniki [0.25 Russian pounds] for big rockets, and 12 zolotniki [0.125 Russian pounds] for small. A beetle should be at hand just in order to ensure that the propellant all falls to the bottom, and the first ramrod is then inserted into the casing and, before the heavy blows, is seated by three light taps of the ram. There follow 25 blows of the ram, raising it to the cord and turning the ramrod after every blow by means of a stick inserted in its head. After these 25 blows there is a pause while the ramrod is raised a little and the propellant is knocked out of it into the casing; then, lowering it again, there follow another 25 such heavy blows, turning the ramrod after each. This procedure is followed for each fill of propellant and for three ramrods. For the fourth, fifth, and sixth ramrods the procedure is the same, but each fill receives 45 heavy blows, with a pause after the 22nd to knock the propellant out of the ramrod. For the seventh and eighth ramrod the same procedure is followed, with 40 heavy blows. When the casing is filled up with propellant, silt is packed above it to the depth of 1/4 caliber by 40 heavy blows, after which the casing is removed from the rod by a windlass and the hole is sealed with resinated flax. Small rockets are stuffed using a 10-pound hand beetle, and following the same procedure: first two ramrods with 35 measured blows per fill, and a pause after 17 to knock the propellant out of the ramrod, then two more ramrods with 30 blows, and a pause after 15, and finally, the fifth and sixth ramrods with 25 blows, and a pause after the 12th.

9. Incendiary compound and its preparation. This compound consists of saltpeter, sulfur, antimony, rosin and oil of turpentine, in the following proportion:

Saltpeter	14 parts
Sulfur	6 "
Antimony	1 part
Rosin	1 "
Oil of turpentine	2 parts

All of the ingredients are separately rubbed very fine and boiled over coals in a stove made for the purpose, on top of which stands a cauldron. After it has warmed up somewhat, its edge is smeared with pig fat, and the sulfur and rosin are placed inside and melted into a liquid. While this is happening, the saltpeter is poured in a little at a time, while stirring constantly with a trowel. When it is sufficiently mixed, the antimony is poured in and the mixture is stirred further. Then, removing the cauldron from the heat onto thick felt, the oil of turpentine is poured in and the mixture is again stirred with a trowel. The cap is filled with the compound while still warm (it should by no means have been allowed to get cold), without disturbing the ignition channel in the rocket casing.

10. Filling the cap with incendiary compound. As noted above, the incendiary compound is to be filled while still warm. The hands are thus smeared with pig fat, and the compound is poured in a little at

a time, packing each fill in with a ramrod some 15 times, and continuing until the cap and the designated part of the casing are full.

11. Attaching the shell and the cap. Before it is secured to the rocket, the cap is prepared as follows: when the compound in the cap has completely cooled and hardened, a hole is drilled in the compound in the middle of the cap, as far as the large orifices, or, if it is desired to prepare all the holes, as far as the last ones; then each of these holes should be drilled through lateral holes to the one made in the middle, and filled with an illuminating compound, packed in as in paper tubes of gunpowder, and prepared by means of a trowel. After this a hole is also drilled through the incendiary compound and silt, as far as the rocket propellant, in the center of the casing. After this is done, the cap is fitted tightly onto the casing and bound tightly with twine, from beginning to end of the notches. After perforating the silt in the rocket as far as the rocket propellant, the shell is inserted into it by means of a tube, the shell tube support having previously been set straight in the silt. Two half-inch bands of sheet iron are placed crosswise over the shell, and it is then attached to the rocket like the cap. The length of these bands should be about 15 inches. All of the orifices in the cap and beneath the rocket are covered with fireproof resinated flax.

12. The shell of an incendiary rocket. The shells should be of the same diameter as the rocket with walls half the thickness of those of conventional cast shells of the same diameter.

13. Weight and size of tails and their attachment to the rocket. The tails are made of pine or some other light wood 2" thick at its upper end, and thinner below, and 7 1/2 times the circumference of the rocket casing in length, planed to form a right tetrahedron. If one moves along the tail away from the casing, the rocket begins to overbalance at a point 4 calibers away from the casing. The tail is then passed through lugs, the two lower of which are heated red hot, and have one hole pierced in each (the lugs are heated and the holes made before filling); the screw fitted to the upper lug is turned extremely tight, and the tail is perforated opposite to the holes in the two lower lugs, through which iron nails are driven. The tails should be made of the driest possible wood, which would keep the weight of a 4" rocket tail down to only 12 pounds, but due to the unavailability of dry wood here, big tails have never weighed less than 14 1/2 pounds, and have been known to reach 16 1/2 pounds. Tails for small rockets weigh from 3 to 4 1/4 pounds.

14. The launcher. The launcher is made of strong dry wood, of a planed bar measuring 7" on all sides and 8 1/2 times the circumference of the casing in length. In this bar is hollowed pyramidally, from one end to the other, a groove of the same length as the tail into which the tail easily fits. The end which is not chiseled through is rounded off as in the trail of a gun-carriage, and is perforated by a hole designed to fit a slide-valve with spring, as in gun-carriages of early design. The depth of this groove is 5", and inside it, towards the bottom, are small rollers on pivots. From its upper end the bottom and sides of the groove are externally bound with sheet iron, and the lower sheet is bent upwards along a line over the surface of the rollers for 6 inches. This flange is rounded at both its ends. The groove is fitted with two legs, attached to a cushion by a bolt. The bolt, passed through the cushion and the groove, connects the legs with the

groove. The legs, for the launchers of large rockets, are made 2/3 the length of the entire groove, while those for small rockets are made 2 1/4 arshin [63"] long.

15. Elevation of the launcher in degrees [launching angle] and range of a rocket. The greatest launching angle for big rockets is 55°, though this can be decreased to 35° and even lower. With a launching angle of 55° a 4" rocket covers a distance of 950 to 1250 sagenes [2220 to 2920 yd], while at 35° it will reach a little over 500 sagenes [1170 yd]. Small rockets with long tails are launched at from 40° to 25°, and will reach 750 sagenes [1750 yd] at the higher angle, and 500 [1170 yd] at the lower.

Small rockets intended to ricochet are cut into a wooden sphere 4" in diameter, but are in other respects like rockets shot in a curved trajectory. They are normally equipped with shells and launched from the ground. Small rockets have been found more convenient for this purpose, since experiments show the large ones to reach no farther, and sometimes, not so far.

Colonel of Artillery Zasyadko

5. PROGRAM OF EXPERIMENTS WITH A ROCKET BALLISTIC PENDULUM FOR THE IMPROVEMENT OF 2-INCH ROCKETS*

A rocket pendulum can be used to determine, for each rocket tested:

1. The time for which the propulsive force acts.

2. The magnitude of the entire propulsive force produced by combustion of the rocket propellant from its beginning to its end, in pud-feet [1 pud = 36 lb].

3. The internal gas pressure in the casing in pounds per square inch of internal casing area, i.e., the successive magnitudes of this pressure at the end of successive arbitrary time intervals, so that the variation of the internal pressure from the beginning to the end of combustion can be represented by a curve, with the abscissa proportional to the time and the ordinate proportional to the internal pressure in pounds. From this can be determined:

4. The limiting maximum gas pressure in the casing.

5. The time between the commencement of combustion and the moment of maximum gas pressure.

From this it is evident that a rocket pendulum can be used to determine:

a) The relationship between the proportionality of the constituents of the rocket propellant, all features of the rocket's internal design, and the parameters noted above.

b) The *minimum possible thickness* (determined by calculation) of the iron in the casing of the rockets tested. **

* AIM Archive, VUK store, entry 40, file 113, sheets 231 — 237.

** From the formula $x = \frac{v \cdot p}{t}$, where x is the thickness of the casing walls, v is the internal diameter of the casing, p is the weight necessary to burst iron for the required cross section, equal to a unit of surface, and t is the limit of the internal pressure in pounds per unit of internal area of the casing.

The features of the internal design of rockets of a given caliber are:

1. Ingredients of the rocket propellant and their proportionality.
2. Density of the rocket propellant.
3. Height of the blind propellant.
4. Height of the ignition channel.
5. Diameter of the ignition channel.
6. Size of the gas exhaust orifices.

There are thus six factors the effect of variation in which on the performance of the rocket propellant is still very poorly understood. To study them fully it would be necessary to perform a number of experiments with a rocket pendulum, varying each of these factors in order to obtain different combinations; but even with a small number of variations in each factor, the number of different combinations would become enormous, there would be no end to the experiments, and the idea would be lost in the mass of results and their applications.

To facilitate the investigation, the variations can be limited, on the basis of such facts as are now partially known, i.e.:

1. For rockets with an exhaust orifice equal to the cross section of the casing, a propellant consisting of pure gunpowder pulp should be used; for weakened propellants, which may be required if the exhaust orifice is reduced in size, two series of propellants should be adopted:

a) Gunpowder weakened by the admixture of varying percentages of carbon.

b) Gunpowder weakened by the admixture of varying percentages of nitre and sulfur.

2. In all possible experiments the density of the propellant should be brought up to the maximum possible limit.

3. The height of the blind propellant should be made equal to the thickness of the propellant about the channel, because the combustion of the blind propellant alone must give rise to a propulsive force whose only appreciable effect will be the production of deviations.

In addition, at the beginning experiments with direct application to the design of rockets with lateral and central tails should be conducted. These experiments can be divided into series:

First series of experiments. Investigations toward the design of rockets with lateral tails and an exhaust orifice equal to the cross section of the casing.

Propellant — gunpowder pulp.

Diameter of the channel — 0.6", 0.8", 1.0", 1.2", 1.4".

Channel height — 3 1/2, 4, 4 1/2, and 5 calibers.

This gives 20 different combinations. Each combination should be tested both igniting the rocket propellant at its edge and igniting it by means of a quick-firing primer, extending to the bottom of the channel, with the rocket covered with resinated flax. This will double the number of experiments, making 40 altogether.

Second series of experiments. To determine the effect of the size of the exhaust orifice in rockets with lateral tails and a base plate with central orifice.

Propellant — gunpowder pulp.

The central orifice in the base plate is taken at 0.8", 1.0", 1.2", 1.4", and 1.6". For each orifice one rocket with a channel in the propellant

0.6" in diameter should be tested, and another the diameter of whose ignition channel is 0.2" less than that of the exhaust orifice in the base plate. For both these rockets the height of the ignition channel should be allowed to run through the values of 3 1/2, 4, 4 1/2, and 5 calibers, giving a total of 40 rockets. In each rocket the two different methods of ignition employed in the first series should be tested, giving a total of 80 rockets for the second series.

Third series of experiments. Investigations of rockets with a central tail and base plate designed for a central tail.

In these experiments the area of the gas exhaust orifice can be taken as the maximum possible permitted by the central tail design, where the tail is screwed on. It must be taken into account that the tail screw must have a diameter of 0.8", while the diameter of the channel will be constant and will be determined by the diameter of the tail screw in the base plate. It must be 0.2" less than this, giving it a diameter of 0.6". The variables will be the proportionality of the ingredients of the propellant and the height of the channel. For the former one can take the two types of propellant mentioned above: gunpowder pulp with an admixture of carbon, and gunpowder pulp with an admixture of nitre and sulfur, allowing six variations in each type. For each propellant the channel can be taken at 3 1/2, 4, 4 1/2, and 5 calibers, giving 48 different rockets for the third series of experiments.

In all of the series of experiments it is assumed that only one experiment will be performed for study of each factor in the internal design of rockets. One successful experiment should be sufficient to determine the relationships sought, for the following reasons.

1. The results obtained by means of the pendulum for each rocket will have all the accuracy that could be desired, due to the design of the pendulum and the means adopted for conduct of the experiments.

2. The results obtained for one rocket, tested on the pendulum, can be allowed with only a small departure from the mean results which would be obtained from many experiments since in carefully built rockets there can be no great variation in the performance of the propellant. It must be incomparably less than the variation in the performance of gunpowder charges, since the rocket propellant constitutes a dense mass, almost unaffected by the various circumstances in which a rocket can be placed during storage; a gunpowder charge, on the other hand, consists of grains susceptible to displacement into a different relative position and subjected more than a mass of rocket propellant to the influence of external circumstances, on account of their considerably greater surface area relative to their mass.

The lack of mean results can be partially compensated for by the familiar graphic method of correcting the experimental results which determine the functional relationship between any variable and another variable depending upon it. This is done as follows:

The experiments of each series, as is evident from the scheme, consist of several classes of experiments, in each of which are tested a number of rockets distinguished from one another by continual variation of just one part of the design. The results obtained for each class can therefore be represented graphically by broken lines, plotting the design changes along the abscissae and the results, along the ordinates. In this way a broken

line will be obtained for the variation of time required for combustion of the entire propellant, another for the variation in the magnitude of the propulsive force, etc.

If these broken lines are replaced by continuous curves running between the points determined, one has an empirical approximation of the truth.

The requirements for the experiments of all three series are as follows:*

For the first series of experiments, casings with an exhaust orifice equal to the cross section of the casing. For this purpose the manually made casings remaining from last year's experiments can be used

For the second series of experiments, casings with a smaller gas exhaust orifice, and five different schemes corresponding to different areas of the orifice. To speed up the experiments, two casings could be used for each scheme, making a total of 10 casings, which would have to be prepared manually at the Sestroretsk plant.

For the third series of experiments, casings with base plates of my design, to finish the rockets used by us, with central tails, until the perfection of Pikte rockets, therefore the number can be confined to 10 casings.

In the casings for the second and third series of experiments the thickness of the walls must be made much greater than is usual, or approximately 0.5", to avoid every danger of an explosion and to conserve the casings.

As these casings have no lugs, they can be filled in one of the Rocket Institute's 3" molds.

The casings for the second and third series of experiments must be fitted with iron plugs on wedges to strengthen the layer of clay which constitutes the blind propellant.

This program of experiments with a rocket pendulum will serve as the basis for a theory of internal rocket construction, which now exists only in the vaguest form. This theory would make it possible to strive systematically for the perfection dependent on the internal design of a rocket. Indeed, the following can be assumed a priori to be prerequisite to the attainment of this perfection:

1. The magnitude of the propulsive force must be the maximum.
2. The time for which the propulsive force acts must be the minimum, provided it is no less than the time needed for the rocket to leave the stand.
3. The time between the beginning of combustion and the moment of maximum gas pressure in the rocket must be less than the time needed for the rocket to leave the stand.
4. The wear and tear on the casing must be as little as possible, therefore the maximum gas pressure in the casing must be as low as possible when the propulsive force is at its maximum, to minimize the wear and tear.

In addition, the increase and decrease of pressure in the casing should occur continuously, and in proportion to the time. It would most likely be best, both from the point of view of maximum propulsive force, and from that of minimum wear and tear on the casing, for the pressure to reach its upper limit rapidly, rising in proportion to the time, then to remain constant, and finally, to fall off rapidly and in proportion to the time, rather than drop instantaneously.

* The three series include 168 rockets, but the number of casings can be far lower, since each casing can be used for a number of experiments.

The external design of a rocket, which implies the weight of the entire fully-equipped rocket, the length of the tail, the position of the center of gravity and its displacement during flight, etc., can be based on known facts unrelated to this subject, on the fundamentals of theoretical mechanics, on the data which I found in previous experiments, and finally, is subject to further experimental research.

A program of investigations towards the establishment of a theory of external rocket design (in the sense used above) will be the subject of another monograph.

15 May 1849.

Captain Konstantinov

6. TAILLESS SIGNAL AND MILITARY ROCKETS*

As is well known, there are other means, besides a tail, for making a rocket fly straight, i.e.:

1. A rocket can be made to fly sufficiently straight by proper situation of the center of gravity alone; this requires only that the center of gravity *a* of a fully-equipped rocket casing be located along the direction of forward motion of the center of the figure *b*, and that through burnout the center of gravity of the entire system, being displaced, not pass behind the center of the figure, nor even coincide with it. If either of these contingencies occurred during flight, the rocket, rather than flying straight, would take the course of a Schwärmer.

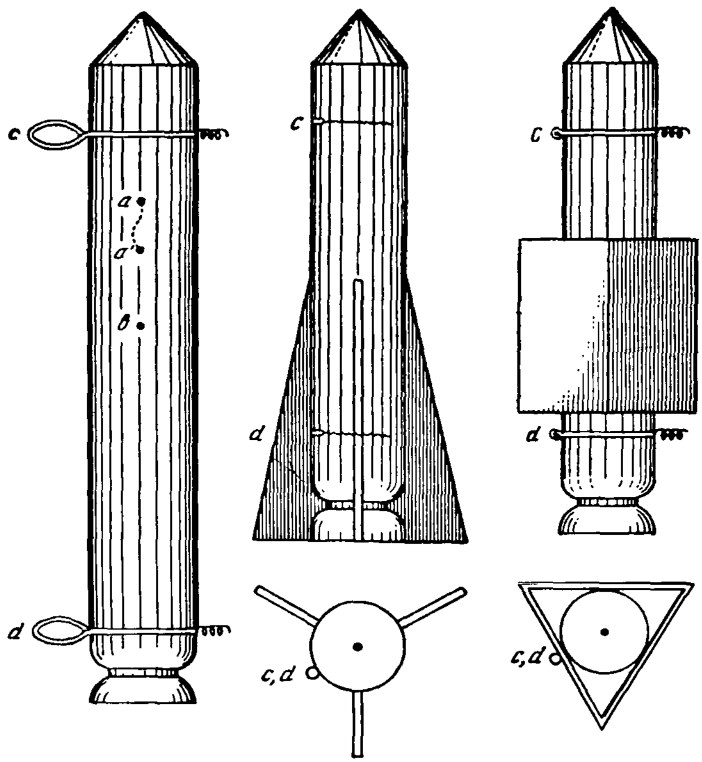
A well-designed rocket, even though it proceeds in a given direction, thus follows a rather winding course. This is particularly due to the fact that the nonconcentric combustion of the propellant causes displacement of the center of gravity, not along the axis of the rocket casing, but along an irregular curve about the rocket axis. To dispel the consequent irregularity in flight, wings are fitted to the lower part of the rocket casing. (I brought details of signal rockets of this type, used by the Sardinian artillery, from Turin in 1840.) These wings increase the lateral air resistance on the lower part of the rocket, thereby maintaining it in the direction of flight.

In place of wings, a certain Vaillant from Boulogne-sur-Mer (Manuel de s'artificier de Vergnaud) conceived the idea of using a triangular prism of thin cardboard, tangent to and secured to the lower part of the rocket.

Pounder signal rockets with wings and with prisms have been repeatedly manufactured in the laboratory section of the general Gunpowder School. For launching two rings of wire *c* and *d* were attached to the surface of the rocket casing and used to launch the rocket from a vertical iron rod secured to the upper part of a stake. The flight of these rockets was always completely satisfactory, and in particular that of the rockets with prisms, which are superior to those with wings in certain important respects, i.e.: they are easier to make, a prism is more easily attached to the surface of a casing, and in addition, rockets with prisms are far easier to transport than those with wings.

* AIM Archive, ShGF store, entry 12, file 37, sheets 32 — 35.

It would be exceedingly useful to bring signal rockets with prisms into actual use, on account of their ready transportability and safety in launching, but the same system is inadmissible for military rockets, because of the insufficient flatness of trajectory. Rockets fitted with wings and prisms can only be launched vertically, or at high angles.



They have very long range at high launching angles, and the insufficient flatness results from the shortness of the rocket. To attain flatness of trajectory in spite of this, the rocket would have to have a velocity near that of an artillery projectile which follows a flat trajectory, and rockets cannot be given such velocities.

When the length of the rocket is increased by a tail, flatness is increased by lateral air resistance on both the ascending and descending arms of the trajectory.

2. Another means for directing rockets without tails consists of imparting to the rockets in flight rotational motion about their axis.

This method reduces the flatness of trajectory even more than the preceding one, since the rotational motion of the rocket about its axis,

produced by the design of the rocket, * always absorbs part of the propulsive force, thereby reducing the action of the propulsive force in the direction of flight, with a consequent reduction in velocity and trajectory flatness.

3. There is yet another method of making a rocket fly straight without a tail. This consists of imparting to the rocket, whose center of gravity is located as in winged rockets, a high initial velocity by means of a gunpowder charge in an appropriately designed launching tube, or, in accord with the caliber of the rocket, in the barrel of a fire-arm or the bore of an ordnance piece. This was Montgéry's idea and was developed by him, though in very incomplete fashion, in his 1825 work on rockets. On the basis of this idea Montgéry proposes rockets of special design, which he terms "rochettes."

The Foss rifle incendiary rockets used by us are a practical realization of Montgéry's idea and probably constitute its only possible application. There is no doubt that the idea could be made a basis for the design of tailless military rockets meant to be shot from light ordnance by a reduced charge or from launching tubes specially designed for this object.

Unfortunately such rockets, in spite of their probably flat trajectories and small deviations, would offer no particular advantages. Shot from artillery pieces, they would constitute an expensive projectile whose cost and difficult maintenance would not be compensated for by its advantages, consisting of the great explosive and incendiary effect of rocket projectiles by comparison with conventional artillery projectiles.

The introduction of rockets as artillery projectiles would lead to an increase in the already existing diversity of ordnance ammunition and this alone is almost a sufficient argument that the idea of shooting tailless rockets from artillery pieces should not be pursued.

The shooting of tailless rockets by a charge from specially designed launching tubes would lead to a special artillery whose character would be particularly notable for having combined the deficiencies of conventional and rocket artillery, without the chief advantages of either. The efficiency of this artillery would thus be less than that of conventional artillery. On the the other hand, although the launchers of this artillery would be considerably easier to move than artillery pieces, they would weigh far more than conventional rocket launchers, with the result that this artillery would have considerably less mobility than existing rocket artillery. Furthermore, so much time would be required to load the launching tubes with rockets that this artillery would be slower in action, not only than rockets, but even than ordnance. This new artillery, constituting something in between conventional and rocket artillery, would be devoid of the qualities which are the reason for the vitality of military rockets, their existence at present, and the urge for their improvement, i. e., the lack of any destructive effect

* Rotational motion about the axis of the rocket can be produced by:

a) Oblique gas exhaust orifices.

b) An oblique surface attached to the rocket, in the stream of the escaping gases.

c) External spacings on the casing to produce rotational motion through air resistance.

d) Screwlike threads on the inner surface of the launching tube and projections, which fit into them, on the surface of the rocket. In all of these cases, careful investigation of the matter shows convincingly that the rotational motion occurs at the expense of the rocket's propulsive force.

on the launcher, and concentration of the reasons for the projectile's motion and its terminal effect in the projectile itself.

6 July 1849

Colonel Konstantinov

7. THE INTRODUCTION AND USE OF MILITARY ROCKETS IN THE NAVY*

The following are the contents of a note on the introduction and use of military rockets in the Navy, read by Colonel Konstantinov, Permanent Member:

1. Comparison of military rockets with conventional artillery

Deficiencies of rockets:

a. Military rockets cost more than rounds fired from artillery pieces.

b. They are more prone to deteriorate through prolonged storage or unfavorable conditions than is artillery ammunition.

c. They are inferior to ordnance both in striking force and accuracy.

d. In large numbers, exceeding 500, rockets have higher weight and volume than those of artillery pieces with their ammunition.

Advantages of rockets:

1. The projectile incorporates its means of propulsion.
2. The small space required for rocket launching.
3. The ready transportability of rocket launchers and individual rockets.

For these reasons rockets, despite their drawbacks, constitute a useful weapon even when conventional artillery is available, since they sometimes make it possible to achieve results unattainable with conventional artillery. Proof of this is furnished by the increasing annual demand for military rockets in the Caucasus, where 6000 rockets are to be sent this year, and measures are being taken to increase the annual shipment to 12,000.

Rockets might have certain special uses in the Navy, e.g.:

1. For operations from rowboats or the shore.
2. For action against ships from shore batteries.
3. For action against the shore whenever the Navy must undertake independent military operations against the shore.
4. For signalling and illuminating.
5. To throw lines.

To examine more closely the utility of introducing rockets in the Navy it would be helpful to conduct experiments on military rockets under the direction of the Rocket Institute and in the presence of observers from the Navy Department. For the purpose of testing rockets in the five instances listed above, at least at first, it would be necessary to limit the tests to 2" rockets, whose use, to the exclusion of other calibers, in the Caucasus, testifies to their being the most perfected of our designs.

For rocket operations on terrain and against ships from the coast the launchers and launching methods now in use are sufficient, but rowboat operations would require new launchers equipped to direct rockets even when the boat is pitching and tossing, and which would protect the ship

* Journal of the Naval Scientific Committee, No. 109, 3 February 1851. TsGAVMF, sotre 162, entry 1, file 285, sheets 4 — 6.

and crew from the rocket's fiery wake. Such a launcher with a percussion mechanism for ignition of the rockets might be built according to the instructions of the Rocket Institute in the Izhorskii Naval Workshops. A list of rockets for the first experiments is appended.*

Colonel Konstantinov

After hearing these remarks the Committee, being of the opinion that military rockets might be of use to the Navy, proposed to present the idea to the scrutiny of the Head of the Chief Naval Staff, requesting his opinion of the following:

1. Allowing the indicated experiments to be performed.
2. Permitting the use of the Committee's funds, up to the sum of 300 silver rubles, required for the manufacture of 170 rockets for the experiments.
3. Communication with the War Department on the subject of having these rockets made in the Rocket Institute and stored there until required, as well as having the Institute supply means for performance of the experiments.
4. Ordering from the Izhorskii Naval Workshop, on the instructions of Colonel Konstantinov, a rocket launcher for use on training ships.

Original signed by the Honorable Chairman of the Committee and the members and authenticated by the learned Secretary.

8. A SHORT NOTE ON MEASURES FOR THE IMPROVEMENT OF RUSSIAN MILITARY ROCKETS**

Military rockets have been in use in Europe for about 50 years, but at present they are everywhere regarded as second-class weapons and no government has yet affirmed the need for any great outlay on rockets. Only in Austria has the influence of General Augustin, who has made considerable improvement in rockets, succeeded in constituting 1/8 of all the field artillery † of rocket batteries; however, the rockets manufactured in Austria are exclusively of small caliber (2" and 2 1/2").

The manufacture of rockets was taken up in France in 1806, after their use by the English at Boulogne. Research on the subject was conducted under the observation of a special commission composed of first-rank scientists, but frequent coups-d'état and, to an equal extent, the extraordinary difficulty of perfecting rockets, have been the reason why rocket research in France has continued to the present day, and the French now have only one rocket battery in the East.

In England rockets are used both by land forces and by the Navy for operations from small rowboats, but the organization of the rocket batteries is unknown to us.

* It goes without saying that further experiments in this area would depend on the success of the first ones.

** AIM Archive, ShGF sotre, entry 12, file 154, sheets 149—160.

† The note communicated this year by the Suite of His Highness Major-General Count Stakelberg shows that Austria's 168 field batteries include 20 rocket batteries.

French and English Congreve rockets are completely different from the Austrian ones both in their appearance and in their performance: Congreve rockets have long range — up to 1600 sagenes [3735 yd] — but deviate considerably from the aiming plane, while the Austrian rockets, with a range of no more than 350 sagenes [820 yd], are distinguished by accuracy.

For a long time we had no information about the Austrian rocket design, which was kept a closely-guarded secret, and although Major Moore attempted to reproduce it in Russia, he failed due to his lack of familiarity with the subject. Finally Colonel Konstantinov, Director of the Rocket Institute, in two trips to Vienna, succeeded in penetrating the secret of the Austrian rockets, which would of course have remained permanently inaccessible to someone less conversant with the business of rocket production.*

Our Rocket Institute was tooled for the production of rockets of the English type, whose military use in appreciable numbers in Russia began in 1846, as a consequence of the requirements of Prince Vorontsov.

Since then about 33,000 Russian military rockets have been manufactured, and they were used with considerable success, in the capture and defense of Ak-Mechet, and at the siege of Silistria, as Prince Vorontsov, Imperial Aide, General Perovskii, and Prince Gorchakov testify. According to the dispatch of Lieutenant-General Brimmer in the battle of Kyuryuk-Dara against the Turks, the rockets with the Cossack Hundreds, on the right flank of the Russian position, not only terrified the enemy infantry and cavalry by their novelty and unexpectedness, but being well-aimed, inflicted real damage on the enemy masses, especially during the pursuit.

It is thus apparent that 2" field rockets, when properly used to supplement ordnance in mountainous and dissected terrain where the latter is not easily transportable, can be quite useful, and Russian rockets are beginning to attain this goal.

As far as long-range rockets, of about 3 1/2" caliber, are concerned, they are generally of little use in the defense of sea caosts because of their considerable deviation in flight and the awkwardness of transporting them with their long tails, and for the additional reason that the extremely limited weight of the projectile these rockets can carry decreases with increase in the range desired. Over long distances rockets cannot carry any greater projectile than a 12-pound shell, whose effect on a ship is totally insignificant. In such cases high-angle fire from artillery pieces is always preferable, since the latter not only strike far more accurately than rockets, but can shoot projectiles of very great caliber. Long-range rockets are equally ineffectual in the bombardment of cities or fortresses, because of the insignificant size of their projectiles, and an enemy can only think of bringing rockets close to the shore in small boats when attacking an unfortified position.

From this it is clear that in our present war with the English and French we have no reason to fear rocket launchings from enemy ships. The newspaper reports of experiments conducted in France on long-range rockets are

* A small printing of the detailed description of the Austrian rockets, with sketches, composed by Colonel Konstantinov, was made by royal order for distribution at the disposition of the Inspector-General of Artillery.

only apparently impressive, but give no assurance of particularly destructive effect, since, as shown above, these rockets can carry no missile substantially greater than a 12-pounder.

The real utility of large-caliber rockets is limited to their application, for demolition purposes, in land attacks or fortress defense, to open a breach in a bank of earth or to destroy the works of those under siege. However, high-quality demolition rockets able to withstand transport and storage cannot be built with the existing equipment of the Rocket Institute.

From 1823 to 1850 Russian rocket production was directed by the Englishman Massingbird-Turner, and throughout this period it remained at the same level. The chief deficiency of the rockets was their rapid deterioration in storage and their tendency to burst in launching, particularly pronounced in large-caliber (3 1/2") rockets. The reason for this is the weakness of the presses, which date back to Moore's days, which makes it impossible to fill the rockets with dry propellant. The compound must first be dampened, and the moisture it contains then results in cracks when it dries.

After 1850, when Colonel Konstantinov, an officer endowed with exceptional abilities and having wide knowledge, succeeded as Director of the Rocket Institute, Russian rocket production made great progress. The concern of this field-officer resulted in much greater accuracy and safety in rocket production than before, brought about uniformity in the preparation of the propellant and all rocket parts, improved rocket launchers and replaced almost all machines by new ones differing from the older models. The only exception to this was the presses, whose construction would have required a mechanical motor and the reorganization of the entire Rocket Institute. The practice of filling rockets with dampened propellant could therefore not be altogether done away with. Konstantinov accomplished all this without burdening the treasury with great expense, and with extremely limited financial assistance. Without enough steady artisans, but annually employing new ones periodically sent to him from various places and from the Guards infantry, Konstantinov nonetheless succeeded in eliminating the premature explosion of 2" rockets filled with damp propellant. *

The manufacture of military rockets is the hardest of all laboratory tasks, and in the Russian artillery only Colonel Konstantinov, dedicating his life to rockets and tirelessly studying them and investigating every possibility for their improvement, subjecting every alteration in their design to careful experiment, is able to bring Russian rockets up to the same level as foreign ones.

Now Russian military rockets are a useful supplementary weapon in the Army, as the testimonies cited above make clear, and although they are less accurate than the Austrian ones, they fly farther, which is essential now that hand fire-arms are so highly developed.

By comprehensive annual experiments in the presence of the Artillery Section of the Military Scientific Committee, Konstantinov laid firm foundations for the final establishment of correct rocket design in Russia. These experiments have required extended periods of time and untiring

* Konstantinov was not responsible for the construction and launching of the 3 1/2" rockets used during the field-engineers' experiments at Peterhof in 1850. The explosion of one of these on the launcher nearly took the life of Adjutant-General Prince Menshikov.

efforts and now Colonel Konstantinov need only be given the necessary means in order to attain the desired perfection. He has not excluded 3 1/2" long-range rockets from his research, and in the experiments performed these rockets no longer burst, although, due to the weakness of the presses which require the use of dampened propellant, the Rocket Institute cannot fully guarantee their quality.

The highest artillery command has not lost sight of the necessity of equipping the Rocket Institute to produce rockets of the desired quality. Profiting from the information about Austrian rockets collected by Konstantinov, and the great experience which he had acquired in this area, the Inspector-General of Artillery permitted him to draw up plans for the design of barrels for the preparation of propellant, new presses, and a steam engine, together with the necessary structures they involve. At the same time Baron Korf, General of Artillery, was petitioning for an increase in the permanent staff of the Rocket Institute, taking into account that the maximum set for it in 1850 was reduced in view of the proposal to found another rocket institute in the Caucasus; since this proposal had come to nothing, the existing staff of the Petersburg Rocket Institute was insufficient. Presentation of the budget and staff schemes formulated was delayed, first, by Prince Vorontsov's proposal to found a special rocket institute in Georgievsk, second, by the very formulation of machinery designs, which required extended study and involved profound engineering ideas, and finally, by the failure to resolve the question of transferring the Rocket Institute and the place for artillery experiments from Volkova field.*

It is inconvenient to leave the rocket institute in its present location not only because it is unsafe and because of the proximity of the connecting railway line, but also because there is insufficient room for the installation of a steam engine and of new workshops. A further point of necessity in favor of the transfer of the rocket institute to a new location is that the installation of a safe heating system in it would involve rebuilding of all the structures, which would in turn mean bringing all rocket production for current orders to a halt...

The following measures must therefore be taken to fulfill the imperial command without delay, and to place our rocket production unquestionably on such a high level that it not only does not lag behind, but even outstrips that of foreign governments.

1) The Rocket Institute should be removed farther from the connecting railway line and built closer to Volkova village. For this purpose the necessary land should be rented from the Volkova peasants, 12 1/2 desyatina [33.75 acres], for an annual rate equal to the yearly income they receive from it, 1541 silver rubles. The ground for the artillery experiments, however, should be left on Volkova field, but the buildings on it should be rebuilt and some new ones erected. The ground itself should be partitioned off and surrounded by a hedge on three sides. The plan of the sections allotted for the cottages should be changed so that they lie parallel, rather than perpendicular to the Tsarskoe Selo railway line, and no fresh boundary line should be drawn between the plots and the testing ground, especially across the latter.

* The order to seek a new location for the artillery experiments and the rocket institute came in 1846 by royal command, as a result of His Majesty's observation, made after a visit to the poorhouse, which was built by a local Civic Group near Volkova Cemetery, that the view from there, on either side of the Tsarskoe Selo railway line, was unsightly.

Leaving the rocket institute and the artillery testing ground at Volkova field would save the treasury the 740,132 silver rubles required to purchase the land of Piskarev. In place of this there would be only a small outlay for rental of the new location for the rocket institute from the residents of Volkova and completion of the testing ground.

2) A rocket institute to be built on the newly chosen site should be designed from the plans and budgets drawn up for this purpose, for the annual production of 12,000 field and demolition rockets of various calibers, with installation of a heating system safe for operations involving gunpowder. According to the estimates, construction of the workshops with assembly of the machines and metal parts, and of the barracks for the artisans would require 755,263 silver rubles, but the cost of commercial structures could be lowered.

3) With foundation of the new rocket institute corresponding new staffs should be assigned, with an increased number of masters, apprentices, and artisans, in accord with the scheme specially drawn up.

4) Until completion of the rocket institute in the new location, rocket manufacture should be continued in the existing institute, using its facilities and attempting no more than the production of rockets with moist propellant, which it is equipped to turn out.

When these proposals will receive preliminary approval from the Emperor, the already existing plans for the new staff and budget of the rocket institute will be presented for final ratification.

9. TERMINATION OF THE MANUFACTURE OF 2" MILITARY ROCKETS*

By order of the Chairman of the Artillery Committee the notes of a member [of the Committee] in charge of affairs refer to the Committee for its conclusion, under the numbers 105, 107, 539, 592, and 653, the replies of the regional artillery commands and headquarters to the question of withdrawing 2" military rockets from use, as follows: Omsk, No. 309/1885, and Turkestan, No. 558/1885 (commands); Irkutsk, No. 2685/1885, Caucasus, No. 2997/1885, and Amur, No. 2835/1885 (headquarters).

The subject arose as follows. In the previous year (1884) the Artillery Committee had been instructed to study the matter of 1500 2" military rockets delivered from Orenburg to Tashkent. Of these a large number turned out to have deteriorated during the journey and to require repair. The Master of the Ordnance therefore requested the Committee to consider the utility of the continued production and use of 2" military rockets, suggesting that in view of the present design and armament of field and mountain artillery it might be advisable to withdraw and discontinue the manufacture of the 2" rockets.

Bearing in mind that military rockets were nowhere used in European wars subsequent to the Crimean campaign, and feeling that their future use would be unlikely, and considering that Russians had used military rockets

* Artillery Committee Journal No. 12, 16 January 1886. TsGVIA, store 504, entry 8, file 1354, sheets 4 — 10 obverse.

primarily in wars with semi-barbarian peoples and that, so far as was known to the Committee, the rockets had been dispatched to the battalions in the field at the request of individuals in command of expeditions, the Artillery Committee, in its journal No. 462, for 25 October 1884, expressed the view that for final resolution of the matter, it would be best to ask the troop commanders in distant regions how much importance they attached to the use of military rockets and whether they did not find the time opportune for their withdrawal, following the example of the European armies.

The aforementioned replies just received show that the commanders of the Omsk, Turkestan, Irkutsk, and Caucasus military regions are all agreed in the view that 2" military rockets are of little value in military action, especially in view of the perfected long-range weapons of our troops, and that their use should be altogether discontinued for the following reasons:

1. The Commander of the Omsk region finds military rockets useless even in Asiatic wars, due to their low accuracy, poor striking force, and extremely unpredictable flight vagaries, sometimes resulting in injury to the troops launching them. A further objection is the difficulty of maintaining them in a proper state of repair during transport, since the propellant deteriorates if it is shaken or exposed to great heat. As a result the rockets frequently explode on the stand or close to it, injuring the attendants. Under such circumstances, it is natural to distrust a weapon which at a decisive moment can cause confusion of which the enemy can readily take advantage. Just such a circumstance was witnessed during the Kokand campaign by Major-General Savrimovich, the present Commander of the West Siberian Artillery Brigade.

2. The Commander of the Turkestan region also regards the sums expended on military rockets as a waste of money, since their unpredictability in flight, the infrequent explosion of their shells and their short range make it impossible for them to compete with rifle fire. Moreover, the bursting of rockets on the stand is dangerous to the attendants. When rockets are used against cavalry their mere appearance in the air frightens the horses and creates disorder, but in war against the peoples of Central Asia rockets do not even offer these advantages, since the Asiatic cavalry is not ordered to begin with, and attacks in an enormous mass, only an insignificant part of which can be affected by rockets launched against it. On the other hand, the delivery of rockets to the Turkestan region is costly, and in addition, formation of the rocket detachments results in weakening of the Cossack units, from which the best men and horses are selected.

As a result the Commander of the Turkestan region feels that some of the most reliable rockets to be found in the depots of the region, together with a few stands and other paraphernalia, should be kept in some of the regional fortifications, in any case, for use against enemy troops in the improbable contingency of the investment of these fortifications; for leaving the rockets in service until they become useless will involve no new expenditure. The remaining rockets, however, in his opinion, should be destroyed, and the stands and other appurtenances reduced to scrap iron and sold.

3. The Commander of the Irkutsk region, while agreeing that production of military rockets should be terminated because of their

low effectiveness in battle, believes that it would be useful to retain the military rockets presently in the regional depots for the event of war with the Mongols and Chinese, whose cavalry is so disorganized that in the absence of artillery military rockets could be of use by impeding the enemy's control of his horses.

4. The Commander of the Caucasus region, agreeing that production of military rockets should be discontinued because of their low military capabilities, and their tendency to deterioration through transport or the influence of temperature, humidity, etc., feels that the existing rockets should be transferred to the disposition of the Commanders of the Transcaspian region and the Turkestan region, where alone occasions for their use can arise, since the chief purpose of rockets should be not so much to strike as to demoralize the semi-barbarian and undisciplined hordes of native cavalry. Previous campaigns have shown, however, that even in this theater of war occasions for the use of military rockets have arisen extremely seldom, and that when they did the rockets were not always successful, since they not only failed at times to inflict injury on the enemy, but endangered the troops using them by bursting on the stand. As far as the use of military rockets in the event of a clash with the Turks or Persians is concerned, it cannot be expected to be of any service since at present not only their regular troops, but also most of their irregular cavalry, are armed with breech-loading rifles characterized by great range and accuracy, qualities which the rockets do not possess.

5. The Commander of the Amur region, while recognizing that military rockets have now completely lost their value in wars with countries whose troops are properly organized and well armed, feels that they can still be of use in the Amur region, since in the event of war there, not only troops drawn up in modern array would be involved, but, for the most part, crowds who could be made to panic by the rockets.

With this attitude, and in view of the fact that the regions of European Russia, in all probability, contain a considerable number of military rockets doomed to destruction, and that their production will again be terminated, while the artillery depots of the Amur region contain at present a total of only 800 rockets serviceable for military use, Baron Korf, Adjutant General and Commander of the region, requests from the Minister of War a disposition for shipment to his region of the greatest possible number of rockets, together with stands and all other appurtenances.

Information. The following is the number of 2" rockets presently to be found in depots:

In the depots of the Omsk region	6057	rockets
" " " " " Turkestan region	2812	"
" " " " " Kiev region	400	"
" " " " " Caucasus region	3425	"
" " " " " Amur region	1061	"
In the Nikolaev Rocket Plant	5650	"
	19405	"

The Nikolaev Rocket Plant has been given an order for the manufacture of 250 2" military rockets in 1886.

After examining all the above and taking into account the opinions of the Commanders of the military regions mentioned with regard to the uselessness of manufacturing military rockets of the type current in Russia, and bearing in mind the thin walls of the rocket propellant forced into the casing, which frequently suffer severe jolts when the rockets, transported in carts, and more particularly, in pack-loads, are carelessly taken down from the horses and put on the ground, thereby inducing cracks in the propellant and ruining the rockets, the Artillery Committee decided:

1) That the manufacture of 2" military rockets at the Nikolaev Rocket Plant now be terminated, and that it be left to the Rocket Plant to make use of those of the remaining machines, lathes, instruments, etc., which can be employed in the manufacture of rocket flares, rescue rockets, and other objects.

2) That in accord with the request of the Commander of the Amur region the 5650 2" military rockets presently in the Nikolaev Rocket Plant be shipped at his disposition and wherever he wishes, with the beginning of summer in the coming year (1886). All of these rockets, which have not yet undergone transport, should in any case be examined, and only those of them should be sent whose appearance indicates that they are in perfect order, although such examination will give no guarantee that after the journey to the Amur region some rockets will not burst in launching. The rocket stands and prescribed appurtenances should be shipped with the rockets, and where convenient, may be taken from the depots of the Caucasus or other regions where they are to be found.

3) The military rockets now to be found in the depots of the Asiatic military regions should, in accord with the opinion of the Commanders of these regions, be retained in these depots or in other places, conformable to the occasion of their being required in battle.

4) The military rockets stored in the depots must unfailingly be periodically (not less than once a year) checked and tested in the presence of an officer in charge of experiments, with their launcher and preliminary drive, in accord with the rules set forth in the description of 2" military rockets written by Captain Stepanov of the Nikolaev Rocket Plant and disseminated in the Committee Journal, No. 409 (1883). This description should be used as a guide in dealing with military rockets and their storage.

10. COMPRESSED AIR ROCKETS WITH SPECIAL GUIDES IN PLACE OF TAILS*

Notes No. 491 and 1176 of the business manager of the Artillery Committee, for 1905, refer to the Committee for its conclusion Colonel Pomortsev's reports of 21 April and 14 October 1905, the first of which deals with the replacement of rocket tails by special guides, and the second of which is concerned with the replacement of forced rocket propellant by compressed air.

From the first report it is clear that Colonel Pomortsev has replaced the rocket tail by a special vane consisting of 4 steel bands (1 mm thick and 50 mm wide), attached at their centers to the 4 extensions of a steel tube, at the ends of two mutually perpendicular diameters. The tangent

* Artillery Committee Journal No. 42, 18 January 1906. AIM Archive, Artillery Committee store, entry 39/4, file 417, sheets 293, 305—307.

ends of the bands are riveted together in pairs, forming a spider on the tube, which is tightly fitted over the lower end of the rocket casing and is securely coupled to it.

The arms of the vane, since they meet small air resistance when the rocket is in translational motion, serve as excellent guides, and since they are lighter than a tail, rockets with a vane of this type, as experiments at the Main Artillery Proving Ground have shown, fly more accurately and farther than rockets with tails. For the launching of vaned rockets Pomortsev built a very light stand, consisting of 4 iron guide strips arranged in pairs in two mutually perpendicular planes, with their inner edges parallel. The rear ends of the guides are coupled by an iron ring and brace strips in the plane of the ring, but the forward ends are free to admit the rocket casing with the required gap, placing the arms of the vane between the neighboring guides. The lower guide strip is connected by means of a hinge to a small tripod, which makes it possible to launch the rocket at any angle desired. The total weight of stand and tripod is about 1 pud [36 lb], but experiment has shown such a light stand to be rather unstable.

In his second report Pomortsev remarks that during his last journey abroad, among other things, he visited several plants in Belgium and France which are concerned with the development of pipes for compressed gases, and that he stayed at the French Société metallurgique de Montbard, near Dijon. This plant is involved in widespread production of pipe and has a special factory for the electrolytic extraction of oxygen and hydrogen. The plant then ships these gases in compressed form to many places in France and Belgium. The director of this establishment, an excellent engineer, was highly receptive to Pomortsev's idea and together they developed a design for a rocket propelled by compressed air.

Attaching a schematic diagram of this rocket, Colonel Pomortsev requests that an order now be given to the French plant, in order to begin experiments on the rockets at the beginning of the coming spring.

The essence of the design is as follows: a seamless steel pipe with a threaded hole in its head serves as a reservoir for compressed air at 200 atmospheres. When filled with air, the pipe is closed by the shank of a steel sleeve which screws into the hole. The sleeve has a disk-like top whose diameter is slightly greater than the external diameter of the pipe. Along the axis of the sleeve is drilled a channel whose upper part is fitted with a screw thread, while its middle, smooth part, of somewhat smaller diameter communicates with the lower surface of the sleeve head by four mutually perpendicular radial ducts in the thickness of the head, whose outflow orifices are arranged with perfect symmetry about the axis of the pipe and diverge downwards somewhat from it. Finally, the lower, also smooth part of the central channel through the sleeve , still smaller in diameter, is closed off by a copper cup whose base rests upon an ebonite disk. This is pressed against the lower edge of the middle part of the channel by the stem of the central screw, whose head is screwed into its upper, threaded part. In the stem of the central screw below is a recess for a percussion cap. When this is exploded by an electrical spark the ebonite disk and copper cup are broken, permitting the compressed air to escape from the reservoir through the radial ducts.

The advantage of placing the exhaust orifices in the rocket head is that the rocket's propulsive force, being applied in front of the center of gravity, contributes to flight stability. The stabilizing vane described above is mounted on the rear end of the rocket, in place of a tail, and a luminous or other projectile is mounted on the disk-like head of the sleeve.

Pomortsev showed, from the numerical data given in his notes, that a 10-cm compressed air rocket weighing 16 to 17 kg, about the weight of a 3" flare, could hold 1 1/2 cubic meters of air under a pressure of 200 atmospheres. The air, escaping through the four radial ducts, 2.5 mm in diameter, is completely exhausted in 25 seconds, giving the rocket an initial propulsive force of not less than 40 kg, or no less than that of a 3" flare, but since it acts for a longer period, the compressed air rocket might be expected to have a longer range.

Opinion of the committee. In its journal for 1903 (No. 554), the Artillery Committee, after declaring itself in favor of experiments on compressed air rockets, voted to allow Colonel Pomortsev 1000 rubles for his experiments. The money was used to build a pump to compress the gases and to finance experiments for the development of stabilizing devices to replace rocket tails, as well as preliminary experiments on rocket propulsion by means of compressed air. Finding his results satisfactory, the Artillery Committee voted Pomortsev another 1000 rubles upon his petition for this sum to enable the completion of his experiments on compressed air rockets.

11. FROM THE REPORT ON A MISSION TO THE NIKOLAEV ROCKET PLANT TO PARTICIPATE IN MAJOR-GENERAL POMORTSEV'S EXPERIMENTS ON THE DEVELOPMENT OF A NEW TYPE OF ROCKET FLARE*

...Summarizing all of the above, I arrive at the following conclusions:

1) Major-General Pomortsev has been conducting experiments toward the development of a new type of rocket for about 5 years, but they have not yet yielded any result, despite the full sympathy of the Artillery Committee in making both the material and technical arrangements for these experiments.

2) After spending about 1 1/2 months at the Nikolaev Rocket Plant on a mission of participation in these experiments, I am convinced of the complete lack of a program in their conduct, which leads me to assert that they will not yield an improved rocket flare in the near future.

3) In order to promote the development of a new type of rocket flare, Major-General Pomortsev should be removed from leadership of the project in favor of someone who has experience in working with gunpowder.

For my part, I can indicate the following instructions to be followed for the attainment of success:

1) Attention should be concentrated on the development of rocket flares, and only incidentally devoted to military rockets (recalling that great importance was formerly attributed to military rockets both here and

* AIM Archive, Artillery Committee store, entry 39/3, file 585, sheets 50/46 obverse — 50/48 obverse.

abroad for the simple reason that the smooth cast-iron artillery then in use produced less effective fire than rockets, whereas the rifled artillery and light machine guns now in use have caused military rockets in many instances to lose all value in war, in the field, and in fortresses). This demands altering the cap with pellets, giving it the most effective shape for reduction of wind resistance, and equipping it with pellets of a stronger (i. e., brighter) compound, since that currently in use is adequate for illumination only over distances not exceeding one verst.

2) To come to the development of a rocket flare, one must first of all study the curves of pressure in rockets for different combinations of ingredients in the rocket propellant, its density of compression, the dimensions of the ignition channel and the size and shape of the exhaust orifices. This will require an improved dynamometer, more suitable for this purpose than that proposed by Major-General Pomortsev.

The research program should be as follows:

a) First of all the pressure curve for the existing type of 3" rocket flare must be found.

b) Then, without altering any other conditions in the equipment of existing rockets, only the size of the exhaust orifices should be varied in order to find, under certain set conditions, the most efficient orifice. Concurrently one can investigate the best shape and disposition of the orifices — whether a single central orifice of a given area, or several orifices grouped symmetrically about the axis of the rocket and together giving the same area.

c) After the most efficient type of orifice has been found, the best dimensions for the ignition channel, all other things being equal, must be sought (i. e., the dimensions which will give the greatest propulsive force). The shape of the ignition channel used in rescue rockets — with a narrow neck in the middle — should be tested.

d) It should be determined whether the currently accepted rocket propellant (72 parts nitre to 14 of sulfur and 20 of carbon) is the best. Practice gives the following indications, which should be used as a guide in seeking the components of a rocket propellant. Carbon should be used in the smallest possible quantity, as a substance which in appreciable quantities will make the propellant too loose and more likely to dry out. The most powerful propellant is gunpowder: 75 parts of nitre, 12 1/2 parts of sulfur and 12 1/2 parts of carbon. This can be weakened by addition of sulfur until it reaches 1/5 of the weight of nitre; further addition of sulfur results in too great an increase of the amount of solid residue, so that the explosive properties of the compound are not reduced in proportion to its adulteration, probably because the holes in the base plates become obstructed by the solid residue. When the limiting quantity of sulfur, equal to 1/5 that of nitre, is reached, further weakening requires resort to carbon, though the amount of sulfur can be increased somewhat with the addition of carbon, since the residue of combustion is then less dense. The propellant chosen should be the best in terms of range, curvature of trajectory, and least likelihood of bursting the casing. The quality of the carbonaceous products used has an enormous effect on the properties of the triple mixture:

Temperature of carbonization	Temperature of combustion	Analysis of coal in percentages				Efficiency of coal in percentages
		Carbon	Hydrogen	Ash	Nitrogen and oxygen	
210°	340 — 360°	72.64	4.70	0.57	22.10	36.16
350	360 — 370	76.64	4.14	0.61	18.44	29.66
432	400	81.54	1.96	1.16	15.25	18.87
1500	600 — 800	94.57	0.74	1.66	3.84	17.31
Melting point of platinum	1250	96.52	0.62	1.95	0.94	15.00

In general it can be said that the most suitable coal is that which is most easily ignited, burns fastest, and leaves the least ash. The extent to which all this depends on the temperature at which carbonization of the wood occurred appears from the above table of Violette, who carbonized almost identical pieces of buckthorn turned out at 150°.

e) The most favorable degree of compression for the rocket propellant must be determined (incidentally determining the absolute density of the compressed propellant). The journals of former experiments kept on file in the Rocket Plant will be of some assistance in working on the second point.

f) In place of tails and guides efforts should be made to utilize rotational motion for the attainment of flight accuracy. For the rotational motion to increase the accuracy of the projectile's translational motion, it must, as is well known, take place about a certain axis tangent to the trajectory, and must be fully developed before the projectile ceases to be guided or, what amounts to the same thing, before the axis of rotation ceases to be supported. Only then will the desired stability of the projectile relative to the direction of firing be achieved.

In ordnance pieces and hand fire-arms these conditions are satisfied by the full development of the rotational motion in the barrel of the gun itself, whose walls determine the position of the axis of rotation. This will not occur, however, if the rotational motion continues to develop and increase when the projectile is no longer guided, or, what would be altogether disadvantageous for flight accuracy, when the rotational motion is produced by translational motion, as, for example, by air resistance against the spiral grooves or through the spiral ducts in the projectiles; for then the rotation can arise about a random axis with no specific orientation to the direction of motion, and instead of correcting the flight of the projectile, can become a new source of deviation. Finally rotational motion set up even prior to the projectile's translational motion in space will be inadequate to regulate its flight if its translational motion continues through action of the propulsive force, whose development in the projectile does not cease, and which causes constant change of the direction of motion of the projectile relative to its axis, even though within very close limits. In this case the rotational motion would undergo constant change from the direction of the translational motion. These considerations, which are applicable to all projectiles, fully explain the failure of the means of applying rotational motion to regulation of rocket flight adopted when military rockets were introduced in all the armies of Europe. These means can be divided into the following three categories:

1) The rotational motion is produced through air resistance by means of helical vanes located on the outside of the casing or tail of the rocket projectile;

2) By means of launching tubes whose inner surface is rifled to accommodate tenons located on the outside surface of the rocket;

3) By means of the exhaust gases, part of which leave the rocket through spiral ducts inside the casing, or by the pressure of the exhaust gases against oblique surfaces attached to the rocket tail.

Experiments on these means of imparting rotation, however, were not conducted carefully, nor were they accorded serious importance, even as applied to artillery projectiles. They were simply regarded as a matter of taste and fashion, and it was supposed that this enthusiasm would pass, to give their due to smooth-bore guns. Modern rifled artillery and the most recent discoveries (the single-gage railway of Bretten and elimination of tossing on ships by means of a rotating gyroscope) give irrefutable proof that the rotation of a moving body or one of its component parts is the surest means of giving it stability. Whichever of the three means outlined above is chosen, the rotation will always be achieved at the expense of the propulsive force which gives rise to the translational motion, and since the propulsive force of rockets is extremely limited, its partial absorption to create rotation will have as a consequence decreased velocity and consequently, reduced range and flatness of trajectory. It seems possible to achieve flight steadiness and long range by communicating rotational motion to a component part of the rocket — a special vane (similar to the propeller on a ship), attached to the casing, which would be made to rotate neither by the air resistance nor by the pressure of the gases giving rise to the rocket's translational motion, but either by appropriate design of the launching stand, or, more correctly, by previously stored work (for instance, by means of a wound spring which is set in motion by the release of a special delay on the stand at the moment the rocket is launched).

4) Our experiments on the improvement of rocket flares need not always be confined to the Nikolaev Rocket Plant; much research might be pursued equally successfully at the Main Artillery Proving Ground during the autumn and winter months. Preparation of the experimental rockets and their dispatch to Sankt-Peterburg for instrument research and direct firing tests might be discussed in correspondence with the rocket plant.

Guards Captain Ennatskii

12. CALCULATION FOR GAS TURBINES WITH A GYROSCOPE*

All of the energy obtained by passage of the gases through the turbine wheel goes to overcome the opposing resistances created by rotation of the two wheels constituting the gyroscope, so that if the diameter of these wheels and the desired velocity of rotation are known, the amount of gas

* AIM Archive, Artillery Committee store, entry 39/3, file 577, sheets 37—42.

flowing into the turbine, the dimensions of the inlet and exhaust orifices and the length of the nozzles through which the gas passes can be determined with sufficient accuracy for initial experiments.

If the diameter of the wheels is taken as 13 cm and the velocity of rotation as 30,000 rpm, the results of Prof. Levitskii's experiments with a Laval turbine 20 cm in diameter can be used.

The frictional surface of the disks can be taken as approximately proportional to the squares of the diameters, so the ratio of the surfaces will be

$$2 \times \frac{13^2}{20^2} = \frac{338}{400} = 0.845.$$

It should also be borne in mind that the peripheral velocity is proportional to the diameters, so that in order to obtain identical values for the friction, the angular velocity for a 20 cm turbine, and consequently, the number of revolutions, must be reduced from the number of revolutions of a 13-cm turbine, in the ratio $\frac{13}{20} = 0.65$, i.e., in this case, $30{,}000 \times 0.65 =$ $= 19{,}5000$. According to Levitskii, a turbine rotating with a velocity of 20,000 revolutions required 4.55 h.p., and one rotating at 17,600 revolutions, 3.33 h.p. Reduction of the number of revolutions by $\frac{240\,000}{20\,000} = 12\,\%$ therefore reduces the work losses by $\frac{12\,200}{455} = 26.8\,\%$.

It can therefore be assumed that reduction of the number of revolutions by 500 (4%) will result in a 9% reduction of resistance, i.e., 19,500 revolutions will correspond to a loss of $4.55 - 0.41 = 4.14$ actual h.p.; multiplying by the reduced surface, we obtain finally $4.14 \times 0.845 = 3.47$ actual h.p.

For small Laval turbines the practical efficiency can be taken as 0.33, but this is when the steam strikes the blade of the turbine with a velocity of about 725 m/sec; in this case the actual velocity of the gases must be taken as about 1400 m/sec, and the efficiency will therefore be about 20%. In other words, the kinetic energy of the incoming gases must be equal to 17.35 h.p. or $17.4 \times 75 = 1305$ kg-m, and since the velocity is 1400 m/sec, gas with a kinetic energy of $\frac{nv^2}{2} = 1305 = \frac{p}{2 \times 9.91} \times 1400^2$. Then $p = \frac{1305 \times 2 \times 9.91}{1\,960\,000} = \frac{25\,944}{1\,960\,000} = 0.0133$ kg/sec. As will be explained below, the combustion products of the rocket propellant, at the greatest permissible pressure of 10 atmospheres, have a specific volume $v = 0.788\ \mathrm{m}^3$, or 788,000 cm^3. Consequently, in place of 1 kg/sec one must put in $0.0133 \times 0.788 = 0.01048\ \mathrm{m}^3$, and since the minimum velocity at the orifice will be about 900 m/sec, the minimum area of the orifices will be $\frac{0.01048}{900} = 0.000012\ \mathrm{m}^2$, or 12 mm^2, and since the gas initially enters at a pressure of about 2 atmospheres, the initial area of the inlet orifices must be $12 \times 5 = 60\ \mathrm{mm}^2$.

In determining the dimensions of the exhaust orifices, it must be recalled that the gases expand to 10 times their former volume, but on the other hand their temperature drops considerably and their velocity increases, so that, following steam turbine practice, one can take the area of the exhaust orifices as 8 times the minimum, or 96 mm^2.

As far as the length of the inlet ducts is concerned, it should be noted that by Rosenhein's experiments a distance of 16 mm between the minimum and exhaust cross sections is insufficient for the expansion of steam from 8 atm to 1 atm, but a distance of 20 mm allows the pressure to descend to 1 atm.

In practice the length of the nozzles is made somewhat greater; in (small) Laval turbines they are made some 30 – 40 mm in length, which is perfectly suitable for the case under discussion.

Now I shall pass to calculation of the volume and exhaust velocity of the gases formed by combustion of the force propellant. Since this propellant is very similar to mine powder, I have taken the data for the latter, which are given in Brink's interior ballistics.

Table XIX (p. 25) notes that the temperature of dissociation is 1682°, while Table VIII gives the products of dissociation of this powder. Making use of the data given by Bellunzo (p. 58) for the characteristic constant of the various products of combustion, I found R for this mixture to be 41.9. One can then determine v from the formula $\frac{p}{R}=\frac{F}{v}$, or $v=\frac{F \cdot R}{p}$. In this case F = 1700 + 273 = 1973, which must be 197.3, p = 10.5 kg, and R = 41.9. Then $v = \frac{197.3 \times 41.9}{10.5} = 788$ which corresponds to 0.788 m^3.

From Table II, compiled from experimental data, and curve IV, we can find the velocity in the minimum orifice to be $1060 \times \sqrt{v} = 1060 \times 0.88 = 932$ m. To obtain the final velocity this figure must be multiplied by 1.85, obtained from curve VI in accord with the ratio of the initial and final pressures

$$\frac{10.5}{1.05}=10.$$

The final velocity comes out to be 932 × 1.85 = 1724 m/sec. The calculated velocities, however, must be regarded as approximate, since the dissociation products of mine powder include not only gases, but also a finely crushed solid residue, constituting by weight 51 % of the ballast which reduces the velocity of the gases.

Still more difficulties are encountered in determining the pressure of the outflowing gases against the rocket, since as far as I know, no effort has been made to determine the causes of the rocket's motion.

There is no doubt that a rocket is set in motion by the reactive force resulting from the outflow of the gases. This pressure P can be expressed by the formula $P=A\frac{p}{g}W$, where p is the weight of the gases leaving per second, g is the acceleration due to gravity = 9.91 m/sec^2, and W is the velocity of the gases through the area of a minimum orifice, in m/sec; A is a numerical coefficient, introduced as a correction for the time taken by the gases to reach the velocity W.

For clarity this equation can be written

$$\frac{P}{p}=\frac{W}{g}\times\frac{1}{t_1}; \left[A=\frac{1}{t_1}\right]$$

and read as follows: the ratio of the pressure created by the gases to the weight of gases leaving per second is equal to the ratio of the velocity

acquired by the gases during one second to the velocity acquired in one second by a body falling freely in a vacuum. If the observed velocity through the minimum orifice were reached by the gases in one second, t_1 would be equal to 1, but of course the gases reach this velocity in a considerably shorter time, so that

$$A=\frac{1}{t_1}>1.$$

Unfortunately too few scientifically organized experiments on rockets have been made to permit determination of the coefficient A, but an approximate idea can be formed from the following argument, based on graphs of the combustion of rocket propellant. The figure of 0.3 in or 8 mm/sec for the speed of combustion of rocket propellant is taken as correct, and it is approximately so, since a 24 mm layer of rocket propellant burns in 3 sec. However, it is highly probable that combustion under high pressure at the end proceeds more rapidly than combustion under lower pressure at the beginning. One may therefore assume that in 0.1 sec, with a dynamometer pressure of 200 kg, a 1.5 mm layer will burn. Then the amount of propellant of density 1.8 g/cm^3 which is burned will be

$$\frac{\pi}{4}(D^2-D_1^2)h+\frac{\pi D^2}{4}\times 0.15=\frac{\pi}{4}(7.6^2-7.3^2)\times$$
$$\times 44+\frac{\pi\times 7.6^2}{4}\times 0.15=(45.365-41.855)\,44+$$
$$+45.365\times 0.15=161.2\ \ \text{cm}^3,$$

and, in fact, $161.2\times 1.8 = 290$ g or 0.291 kg, as we know; the amount of gases obtained is $0.29\times 0.51 = 0.148$ kg.

Substituting in the formula $A=\frac{Pg}{Wp}$ the values $P = 200$, $g = 9.91$, $W = 930$, and $d = 0.148$ gives

$$A=\frac{200\times 9.91}{0.148\times 930}=\frac{1882}{137.6}=14.4\,.$$

The area of the exhaust orifice in a 3" rocket is 11 cm^2, or 0.0011 m^2, while the exhaust velocity of the gases after 0.1 sec is 930 m/sec, so that in 0.1 sec, 0.1023 m^3 of gases, weighing 0.148 kg, will flow out. Consequently, the specific volume $V=\frac{1023}{1480}=0.691$, which corresponds to a pressure

$p=\frac{F\cdot R}{v}=\frac{197.3\quad 41.9}{691}=\frac{8274}{691}=12$ kg, or 11.5 atm, which is close to the assumed figure of 10 atm.

The mean surface of combustion at this time was $23\times 44+45 = 1057$ cm^2; therefore, 1 kg of pressure is obtained per 5 cm^2 combustion area at 11 atm.

That is why I chose as normal combustion area in my cylinders 1500 cm^2, with an exhaust orifice area designed to give an internal pressure in the casing of about 10 atm.

The pressure on the rocket is found to be about 300 kg, i.e., 5 times the weight of the rocket. With a different propellant this ratio will change,

but it will always be possible to determine the numerical coefficients if a few accurate graphs are drawn.

9 September 1909

N. Gerasimov

13. RESULTS OF TESTS OF ROCKET FLARES WITH GUIDES DESIGNED BY MAJOR-GENERAL POMORTSEV, CONDUCTED BY THE NIKOLAEV ROCKET PLANT DURING THE YEARS 1908 — 1909*

The Artillery Committee Journal No. 637, 1908, is devoted to the subject of Major-General Pomortsev's petition for continued testing of the rockets of his design. The Committee decided: 1) That the experiments of the near future at the Nikolaev Rocket Plant and the Ochakov Proving Ground should be primarily on rocket flares running on a burning propellant and fitted with guides; 2) That, since Major-General Pomortsev's participation in the experiments would be helpful, and in view of his desire to continue the experiments, the rocket plant should be advised to follow his guidance and to cooperate in performing the experiments; 3) That the expense for the instruments which Major-General Pomortsev will have to order for his rocket research should be borne by the Treasury, the orders to be placed after information to be provided by Major-General Pomortsev has acquainted the Committee with the design of the instruments.

At the instance of the Chairman of the Artillery Committee, in a 1909 memorandum of the business manager (No. 911), the report of the Nikolaev Rocket Plant dated 15 May 1909 (No. 885) has just been referred to the Committee for evaluation. The report includes an appendix dealing with the experiments on the development of Pomortsev rockets, performed by Lieutenant-Colonel Karabchevskii and the plant mechanical engineer Demenkov, during the period 1907—1909. The report presented also includes tables, sketches, and graphs,** and incorporates the following remarks:

1) At the very outset of the experiments, before casings, stands, dynamometer, etc., were ordered, Major-General Pomortsev allowed the following inaccuracies and errors:

a) The weight of an iron riveted casing for a 3" rocket flare was assumed to be 12 pounds, while the actual weight is about 8 pounds.

b) Major-General Pomortsev thought that an iron riveted casing produced by the rocket plant would withstand a maximum pressure of 15 atm; actually it can withstand a pressure of about 80 atm, i.e., more than 5 times what was assumed.

c) In the casings delivered from the Montbard factory in France, the lower, elongated part turned out to be so flimsy that the rocket plant had to cut off this part of the casing and machine an iron base plate of

* Artillery Committee Journal, No. 86, 27 January 1910. AIM Archive, Artillery Committee store, entry 39/3, file 585, sheets 265—437 obverse.

** In this edition the tables, sketches, and graphs are omitted, but they are preserved in the AIM Archive, Artillery Committee store, entry 39/3, file 585, sheets 284—433.

appropriate shape, which was then secured to the casing by pressing the casing into the groove of the base plate and rolling the ends of the casing over the base plate. These operations greatly increase the cost of the Montbard casings.

d) The Rocket Plant calls attention to the fact that in his report on rocket flares in current use Major-General Pomortsev mentions those having no practical application, i.e., with a range of only about 450 sagenes [1050 yd], as a result of which they serve more to illuminate whoever fires them, while rocket flares underwent their baptism of fire only most recently in the Russo-Japanese War, and particularly at the defense of Port Arthur. Although the plant possesses no official data on their performance, both in the Russian descriptions of this defense and in the descriptions of foreigners in the Japanese besieging army, the testimonials to the performance of the rockets are most enthusiastic. In order to avoid making unfounded statements, the plant presents a dozen or so descriptions of the performance of the rockets at the siege of Port Arthur, extracted from the current press.

2) Experiments on rockets with guides at the end of 1907 and in 1908 and 1909 were continued by Karabchevskii and Demenkov without the participation or direction of Pomortsev.

After the 1907 experiments at the Rocket Plant, in which Pomortsev and Ennatskii participated, the Plant set as a goal for the same year repetition of the experimental launchings of rockets with guides. Since the earlier experiments had shown the lower part of the Montbard casings to be unstable, it was replaced by a machined base plate secured to the casing, with a single central exhaust orifice 1 inch in diameter. These base plates are shown in Figures 1, 2, 3, and 4 (sheet 3). Eight casings with such base plates were made, filled with propellant, and fired, hooked up to a dynamometer. The pressure they produced was so great that the arrow of the recorder flew off the drum, and neither the curve nor the maximum pressure could be determined. The casings suffered no damage.

Thirty casings modified as described above were launched at the Ochakov Proving Ground on 18 October 1907, with the results shown in Table 13. The rockets were launched from stands modified so that the lateral faces were connected by iron arcs, while the lower face was considerably lengthened (sheet 1, Figures 1 and 2). These changes in the stand were made because the irregular flight of the rockets with guides in the first launching was attributed to imperfections in the stand, and in particular to its instability and excessively short sides.

In examining the results of the experiments, Karabchevskii and Demenkov conclude that on the whole the launchings of 18 October are less satisfactory than those of the first launchings (5 September), when the flight of the rockets was more uniform. The failure of the later launchings was attributed to the small diameter of the guides (about 3", or considerably less than in the first launchings) and the fact that the stand was still short. The plant cannot pursue its experiments in the winter because it lacks heated workshops, and because Ochakov is unavailable for rocket launching experiments. However, so as not to waste the time, the winter of 1907—1908 was devoted to experiment on the application of circular and radial guides to signal rockets of current design.

Such rockets were launched on the field of the Rocket Plant on 21 January 1908, with the results given in Table 4.

Throughout 1908 the Rocket Plant used a dynamometer to study the pressure developed by the existing types of rocket flares with different combinations of ignition channel length and cross-sectional area of gas exhaust orifices. The dynamometer was installed at one end of a tube with an accurate sensitive manometer, which showed the maximum pressure in the casing; the dynamometer pen was replaced by a pencil and the tracing of the curve was perfectly clear.

Some 80 rockets were burned out under different conditions, with the results shown in Table 5.

From this table the Rocket Plant concludes that the optimum combination is a central exhaust orifice 1 1/2" in diameter with an ignition channel 1/2" in diameter; decrease in the size of the exhaust orifice results in reduction of the useful pressure, and at a diameter of 1/2" the casing bursts. Increasing the size of the exhaust orifice beyond 1 1/2" diameter results in a drop in pressure.

The most recent experimental launchings of rockets with various types of guides were held by the Rocket Plant on 27 April 1909, at Ochakov. Altogether 38 rockets were launched under the following conditions. A long cast-iron tube, instead of the former short stands, was used as launcher (sheet 1, Figure 13). Ten rockets, whose caps were filled with 80 1 1/2" pellets, and with sulfur instead of an explosive charge, were launched in the daytime at the proving ground, and their range and deviations from the line of aiming were determined. Twenty similar rockets, whose caps carried an explosive charge, were launched at night from a marine battery.

The results of this launching are shown in Table 6, from which the Rocket Plant has drawn the following conclusions: 1) Rockets with caps of the old type do not have so long a range as those with elongated caps of smaller diameter, in spite of the fact that the total loaded weight of the old caps, at something over 20 pounds, is less than that of the new ones. This is to be explained by the lower resistance area of the latter. 2) Some of the rockets with guides, rather than a tail, flew straight, some deviated, occasionally very greatly, from the directrix, and 7 rockets, upon leaving the stand, bit into the earth as if it were water. 3) The range was the same as in the first two launchings at Ochakov, i.e., up to 2 1/2 versts [8750 ft]. 4) The stand consisting of a cast-iron tube, although better than previous types, has the drawback that a circular guide requires for its fitting (the edge extending from the external ring to the thick ring by which the guide is fitted onto the rocket casing) four slits along the length of the tube. These parts become very unstable, and the least jolt they receive is communicated to the rocket as it leaves the stand, i.e., at the most important moment for acquisition of the proper initial direction.

The fact that the center of gravity of a rocket with a guide coincides with the center of the body, making the rocket generally unstable in flight, is a great contributing factor, in the opinion of the Rocket Plant, to such irregularity in the flight of the rockets.

The center of gravity of a 3" rocket flare lies on the casing beneath the cap, at a distance of 20 3/4" from the vertex of the cap cone, and 73 3/4" from the tail cone. It is 53" distant from the center of the body. In rockets

with guides the center of gravity is on the casing at a distance of approximately 22 3/4" from the orifice and 22 1/4" from the vertex of the cone, i.e., it almost coincides with the center of the body.

This is the chief reason why graze bursts occur with rockets with guides, since at the least provocation the rocket head tips forward, causing the entire rocket to overbalance, and it falls to the ground upon leaving the stand.

Opinion of the committee. After consideration of the report of Lieutenant-Colonel Karabchevskii, Head of the Gunpowder Workshop of the Nikolaev Rocket Plant, on the experiments of 1907—1909, concerned with the development of rockets with guides designed by retired Major-General Pomortsev, the Artillery Committee has reached the following conclusion:

1) At its beginning the report mentions the inaccuracies admitted by Major-General Pomortsev even before the beginning of the experiments on rockets with various types of guides, as well as when the experiments were begun in 1907, to be dismissed only in 1908, when continuation of the experiments was placed in the hands of the workers of the Rocket Plant.

2) All of the experimental launchings of rocket flares with guides instead of tails, conducted at various times at Ochakov, can be represented for clearness in the following table.

As early as 1907, before the beginning of the experiments in prospect at the Rocket Plant, the Artillery Committee, having in mind the results of the successful preliminary research of Major-General Pomortsev on the application of tailless guides to rockets, anticipated the collection of data which would make possible mass production of the new rockets. The 1907 experiments at Ochakov did not justify these hopes: the accuracy of the rockets with guides, as the table shows, was highly unsatisfactory, with 60 % of the rockets launched undergoing considerable deviations from the aiming plane. The remaining 40 %, although they kept to the directrix, showed such extreme disparity of range that they were scattered over an area of some 20 square versts [app. 9 square miles].

In the Artillery Committee Journal No. 637, 1908, where the results of the first launching of rockets with guides are discussed, the Committee, for the fullest possible illumination of the question of using guides for rockets, in view of the fact that rockets with guides have approximately double the range of those with wooden tails, expressed itself in favor of continuation of the experiments for final clarification of the matter.

The results of the two subsequent experimental rocket launchings, as the Rocket Plant's report makes evident, also failed to give satisfactory results, in spite of the removal of all the causes to which Major-General Pomortsev and Lieutenant-Colonel Karabchevskii attributed the failure of the first launching, by considerably lengthening the launching stand, increasing the diameter of the guides, and employing them in the most various forms. Only 20 % of the rockets in the second series of experiments, and no more than 14 % in the third, flew straight.

3) The use of guides on signal rockets, which are launched vertically, gave good results: the altitude achieved was greater than that of signal rockets with a single wooden tail, and no less than that of signal rockets with two short lateral wooden tails.

4) The initial research on the best dimensions for the ignition channel and size of the gas exhaust orifices, in the first experiments of 1907, gave no solution to this problem. Table 1, appended to the Artillery Committee Journal No. 637 (1908) does not make it possible to come to any definite conclusion, since even after improvement of techniques for filling the casing with propellant and change of the parts of the casing, different and unexpected pressure values were still obtained. The subsequently repeated experiments on burning out a considerable number of rocket casings to dispel some of the factors obscuring research on the question, and performed by the Rocket Plant in 1909 (Table 5), make it possible to determine some of the optimum parameters: a) The gas exhaust orifice should be central, and for our 3" casing its size should be approximately equal to the sum of the areas of the six orifices used in current practice. For six orifices each 5/8" in diameter, this comes to 1.84 in^2, which gives the best diameter for a single central orifice as 1.5". b) For the existing dimensions of the rocket casing, the most advantageous size for the ignition channel will evidently be that presently in use, i.e., diameter 1" and length 15".

5) The adoption of a modified cap with pellets was extremely effective. Its dimensions are: length to vertex of the cone, 21 1/8", principal section of the cap, 17", and its base, 4 1/8"; diameter of the cap, 4". For greater strength the bottom of the cap is a disk of the same iron as the casing. It contains 80 1 1/2" pellets, which are arranged in 11 rows of 7 pellets, 3 being placed in the base. The empty cap weighs about 3 pounds, and the pellets, about 14 pounds 50 zolotniki [14.52 pounds]. The explosive charge, slow-match, etc., have a total weight of about 1 pound, so that the loaded cap weighs about 18 1/2 pounds. On its external face the bottom of the cap has a threaded stem, which screws into a ring pressed into the casing, in order to fasten the two together. This is done on the spot when the rocket is being readied for launching.

This review of the Nikolaev Rocket Plant's report on the numerous experiments performed with rocket flares fitted with guides has convinced the Artillery Committee that substitution of the proposed guides for tails, while it increases the range of the rocket flares, makes their flight irregular. The Committee therefore thinks it opportune to terminate these experiments.

The existing experimental data, taking into account both the Artillery Committee Journal No. 83 for 1908 and the results of the most recent experiments at the Rocket Plant, lead the Committee to propose that further experiment for the improvement of 3" Russian rocket flares of current design be conducted under the following conditions:

1) Instead of the currently employed cap 6" in diameter one should use an iron cap 40 mm in diameter, and of such length as to accommodate 10 rows of 7 pellets each, with 3 in the base, giving a total of 73 pellets. With 11 rows of 7 pellets and three in the base, giving a total of 80 in the cap, an arrangement actually built at the plant, the cap weighed almost 2 1/2 pounds more than the current design, with a total weight of about 18 1/2 pounds. The alternative proposed above will give perfectly adequate illumination, as in the currently used type of cap, without any increase in its weight (about 16 1/2 pounds). The base of the cap should be ogival in

form, with the radii of curvature used in artillery projectiles of the same caliber. The cap should be attached to the casing by means of a threaded shaft in the bottom of the cap, which is screwed into a ring set into the casing by pressing the edges of the latter around it and rolling them over. For greater durability the bottom of the cap should be made of casing iron, in the shape of a disk, with an orifice for a time-fuse.

2) The casings for these experiments are among the seamless ones remaining at the Rocket Plant from those ordered from the Montbard factory in France. These casings must be tested after being cut to the length of the 3" rocket flares in current use, with ignition channels of identical diameter and length, and of increased length, since in these latter, increase in the length of the channel will result in an increase in the gas pressure in the channel, and consequently, will increase the rocket's range and regularity in flight. When the length of the ignition channel is increased, the area initially ignited, and therefore, the quantity of gas initially formed upon ignition, are increased, and in this case the diameter of the ignition channel may have to be changed from the former 1" to something less.

The base plate with a central gas exhaust orifice must be made separately and attached to the casing by pressing and rolling over it the casing's trailing edge. The diameter of the orifice should be 1 1/2", giving it an area of 1.84 sq in [sic].

3) The rockets should retain a wooden tail coaxial with the rocket. A bushing with three arms converging in a threaded hole at its end is secured to the rear edge of the rocket, and a shaft seated on the rocket tail is screwed into this hole.

Since in these rockets the cap filled with pellets will be longer, thereby shifting the rocket's center of gravity nearer to its head, the length and diameter of the tail must so be chosen as to move the center of gravity backwards. In this way the rocket's axis can be made almost to coincide with the direction of motion until the moment the rocket bursts. The rocket will then constantly move forward, and the effect on the flight of these rockets, arising from the application to them of the old unchanged tail, will readily be eliminated.

These rockets clearly consist of three fundamental parts which are readily dismantled: cap, casing, and tail. They can therefore be packed compactly, and are correspondingly easier to transport.

The following should be noted with regard to the arrangements for these experiments: the Nikolaev Rocket Plant will cease to operate on 1 January 1910, when its activities will be transferred to the Shostensk Gunpowder Plant. The proposed experiments call for the filling of a certain number of rocket casings with an inserted base plate having a central orifice 1 1/2" in diameter, and an end whose external surface is threaded for a bushing. Since all of the proposed changes in the casing, both for the seating upon it of the cap, and the attachment of the tail, must be made before it is filled with forced propellant (the various modifications are hardly feasible after filling, in view of the danger involved), conduct of the experiments in their entirety will be impossible until the establishment of rocket production at the Shostensk plant. However, it would be as well to request the Nikolaev Rocket Plant now, if there remain from the experiments of the past few years, 1) 3" seamless steel casings of various lengths with a ring for attachment of a cap filld with pellets and a base plate with central orifice

inserted into their forward and rear ends, respectively, filled with rocket propellant, and with ignition channels of various dimensions; 2) caps, about 4" in diameter, with pellets 1 1/2" in diameter, and with a bottom modified so that it can be screwed into the ring pressed into the upper part of the casing; 3) 860 1 1/2" pellets. If these parts are to be found in the plant, they should be shipped to the Sankt-Peterburg ammunition dump, to be placed at the disposition of Section V of the Committee. Even should these items be unavailable, the plant should nonetheless ship, as indicated above, 25 finished 3" rocket flares.

14. GERASIMOV'S GYROSCOPIC ROCKET*

Two memoranda, of 9 June** and 30 June of the present year (the second superseding the first) presented by Gerasimov and dealing with his gyroscopic rocket design, have reached the Commission for its evaluation. The content of the second memorandum, submitted by Gerasimov to the Chairman of the Commission, is as follows:

Regarding his rocket design, on the basis of experiments, as fully developed, Gerasimov requested his friend Vice-Admiral Bubnov, the Secretary of the Navy, to assist him in the conduct of a firing experiment to determine the accuracy of his rockets, producing the metallic rocket parts for this purpose in the Navy Department plant. In reply to his memorandum of 28 June, His Excellency resolved that "The conduct of the experiments should be supported, and an order given to the Obukhov plant to manufacture one hundred rockets, the expense to be borne by the experimental fund." Subsequent negotiations revealed that the first installment of some 20—30 rockets would be ready about the middle of September of this year. To equip these rockets Gerasimov requested that the Shostka Gunpowder Plant be given an order for the manufacture and delivery to the Okhtensk Plant of the following quantity of powder, granulated like rifle powder.

Rocket propellant	40 pud [1440 lb]
Compound of 52% nitre, 18% carbon, 30% sulfur	10 pud [360 lb]
Compound of 62% nitre, 18% carbon, 20% sulfur	3 pud [108 lb]

The last variety of powder is desirable for the compression of small cylinders for experiments, in order to give the gyroscope greater velocity of rotation.

Mr. Gerasimov requests the Okhtensk Gunpowder Plant to give instructions for the pressing of cylinders for the rockets out of the powder which is to arrive from the Shostka plant, and that for this purpose the molding workshop now be readied, in order to be able to undertake this work from the middle of August. At present, as Mr. Gerasimov knows, the molding workshop is closed for lack of work. It is desirable to alert the Experimental Commission now of forthcoming work for continuation of

* Journal of the Commission, 3 July 1912. AIM Archive, Artillery Committee store, entry 39/3, file 577, sheets 342—344, 348—349.

** Communicated in accord with a note from the business manager of the Artillery Committee, dated 16 June, this year, No. 1131, for evaluation by Section V of the Committee.

the experiments and equipping the rockets. Mr. Gerasimov requests that this work, and supervision of the pressing, be entrusted to Nedzel'skii, the Provincial Secretary, who has been concerned with such matters up to now.

Mr. Gerasimov requests the gun factory to give instructions for shipment of whatever tail fuses remain there to the Obukhov Plant, and for the adjustment of the instrument for determination of the rocket's gyroscopic properties.

According to the decisions of the Commission, in the journals for 1909 and 1910, the program for elaboration of Gerasimov's rockets must include:

1) The development of a type of gyroscopic rocket and study of the properties of the gases formed by combustion of the forced propellant.

2) The manufacture of a rocket stand.

3) The presentation by Mr. Gerasimov, after development of his rocket, of 30 rockets to the Main Artillery Proving Ground for firing tests.

In its journal for 21 December 1910, the Commission, summarizing the results of all previous experiments, arrived at the conclusion that experiments with Active State Councillor Gerasimov's rocket are incomplete, and that there are no indications of confidence that launchings of this type of rocket will yield favorable results.

Gerasimov's above-mentioned memorandum coincided with the expenditure of all the material for conduct of experiments with his rocket (i.e., gyroscopes, casings, and pressed cylinders) in his possession, and the Commission therefore finds it necessary to present in the present journal the results of all the experiments performed from 21 December 1910 (when the Commission's last journal was composed) until the last gyroscopic rocket test, which was to have taken place on 26 June 1912.

The experiments of the past year and a half took place at two locations: the Experimental Commission of the Okhtensk Gundpowder Plant (where the rockets were burned out on the spot), and the Main Artillery Proving Ground (where the rockets were launched from the stand).

From December 1910 to 2 June 1911 the experiments were performed exclusively by the Experimental Commission, and attempts were made to change the powder of the small cylinders 118 mm in diameter, which would have turned the gyroscopes well and ignited the big cylinders; but the French powder for the small cylinders, composed of 52 parts nitre to 18 parts carbon and 30 parts sulfur burned very slowly (a small cylinder took 45 seconds to burn), and the gyroscope failed to rotate. At first the small cylinders, of the same compound, were ordered from the Shlissel'burg Gunpowder Plant, but when they were tested in the rocket, the latter burst. The same cylinders, of the same gunpowder compound, were then ordered from the Okhtensk Gunpowder Plant, while at the same time small cylinders of gunpowder were again obtained from France, with the composition 62 parts nitre to 18 parts carbon and 20 parts sulfur. But when these latter were burned in a rocket together with the big cylinders, the rockets burst after 1/2 second.

From 2 June to 22 July 1911, small cylinders manufactured by the Okhtensk Gunpowder Plant were tested together with large cylinders of French powder, in the ratio 52/18/30, at the Main Proving Ground. All of the rockets launched burst on the stand, and the gyroscopes failed to rotate.

Because of these results the design of Gerasimov's rocket was modified, and the small cylinder, which was to start the gyroscope rotating while on the stand, was placed inside an iron cap screwed onto the bottom of the rocket; as a result all of the gases formed by the combustion of this cylinder flowed exclusively into the gyroscope compartment, and ignition of the big cylinders took place through an orifice in the lid of the iron cap.

This change in the design, mentioned in Gerasimov's report of August 1911 to the Chief Artillery Administration, was approved by Section V of the Committee, and 9 rockets of the new design (without gyroscopes) were manufactured at the Sankt-Peterburg gun factory. It was decided to order 30 more of the (French) big cylinders, which by this time, had been almost all used up, from the Sevran Livry plant (with 52/18/30 propellant), and supervision of their manufacture was entrusted to Colonel Bordelius, the Artillery Receiver, who happened to be there. (These cylinders have not yet been delivered.)

By the beginning of November 1911 the rockets ordered from the gun factory were ready. These rockets were fitted with the remaining large French cylinders and with small cylinders compressed at the Okhtensk Gunpowder Plant (all with propellant in the ratio 52/18/30). When individual small cylinders were tested in the rockets the internal pressure and time of combustion were determined. A charge 70 mm high and 88 mm in diameter burned for 8 seconds, giving an internal pressure of about 6 atmospheres. Combustion of these charges made the gyroscope rotate. When rockets of this design and equipment were subsequently tested at the Proving Ground, the rockets burned out completely without leaving the stand. It was suggested that imperfections of the stand might have been responsible for the rocket's being jammed on it.

By this time all of the big French cylinders had been used up, and upon Gerasimov's petition Section V of the Committee decided that until delivery of more cylinders from France, the large cylinders too would be pressed in the molding workshop of the Okhtensk Gunpowder Plant.

Meanwhile, at Gerasimov's instance, 3 pud [108 lb] of powder for the cylinders was ordered from the Shlissel'burg and Shostka Gunpowder Plants (composition, 52/18/30). The stroke of the piston in the molding workshop did not permit pressing of cylinders of the full height (250 mm), and they had to be prepared in parts in the form of rings, inner fuse, and a solid bottom.

At first the parts were joined only by glueing, and in all tests, both by the Experimental Commission, and at the Proving Ground, all of the rockets burst on the stand. Later, when the rings were pressed, a thin layer of graphite was pressed in at the joints.

Two rockets thus manufactured were tested at the Proving Ground in January 1912, but one altogether failed to leave the stand, while the other, after flying forward some 70 sagenes [163 yd] and falling to the ground, turned back and fell a second time some 50 sagenes [117 yd] behind the stand.

In order to avoid the reproach that the rockets were held back by the stand, in view of the possibility that the rocket was jammed by the stand's guides, the Commission proposed in all future experiments to launch the rockets from an open chute. The results of several chute launchings in February, March, and April, were as follows: the rockets either burst on the chute, burned out without leaving the chute, or achieved the insignificant range of about 70 sagenes [163 yd].

At the end of April the design of the rocket was further modified by removing the small cylinder from the bottom and so placing it that the gyroscope served as its extension. The first experiment with such a rocket resulted in bursting of the propellant cylinder, as a result of which the cylinder was manufactured as a whole.

At this time Gerasimov voiced the desirability of replacing the propellant formerly used for the small cylinders by the stronger propellant used in our 3" rockets, and a small quantity of this was ordered from the Shlissel'burg and Shostka Gunpowder Plants.

The rocket propellant sent from the Shostka Plant was too fine for Gerasimov's rockets, since under compression in the molding workshop its density remained low and the rockets fitted with cylinders made of it burst on the spot.

Finally, four last launchings of rockets from a chute were held in June 1912. The large cylinders were compressed from 52/18/30 propellant at the Okhtensk Plant, and the small cylinders from rocket propellant (manufactured at the Shlissel'burg Plant). The results were: 2 rockets left the chute, somersaulted in flight and fell at a distance of about 250 sagenes [585 yd]. One of these rockets left the chute exceedingly fast, so that the small and large cylinders were ignited simultaneously (the whistle of the gyroscope was not heard). Of the two remaining rockets, in one only the small cylinder burned, and the large ones failed to be ignited (a layer of paraffin had been pressed into the bottom of the iron cap to prevent rapid ignition of the large cylinders, and the rocket did not even leave the stand); in the other, the electrical sparkplug failed to ignite the small cylinder, and after three attempts to fire the rocket, breakage of the tube containing the electrical sparkplug prevented its launching.

These data on the testing of Mr. Gerasimov's gyroscopic rockets have brought the Commission to the following conclusion.

Both preliminary experiments on burning out of rockets on the spot (with instrument determination of the propulsive force and the internal pressure) and experimental launchings from a stand or open chute have so far given no satisfactory results whatsoever, in the form of appreciable range, however short, or of accurate flight (in both of these respects these rockets have proved inferior even to our old-style 3" rocket flares).

It is impossible to say whether the exclusively unsatisfactory results constantly obtained are to be blamed on the design of the rocket's metal parts, on the method of equipping it, or on the choice of a gunpowder compound; in any case, the rocket as a whole, together with the stand, must be regarded as insufficiently developed, and there are almost no indications, as was the case a year and a half ago, of the possibility of obtaining favorable results in experiments with it.

In view of the above, without presently giving an opinion as to the final termination of experiments with Mr. Gerasimov's gyroscopic rocket, the Commission, bearing in mind Mr. Gerasimov's request that the Navy Department order casings with gyroscopes for rockets of his design, and that he is requesting that a warrant for order of the necessary powder and rocket propellant be issued, feels that such a warrant can be given if the Navy Department will order the rockets.

Meanwhile the Commission is taking heed of the fact that so far no propellant suitable for Mr. Gerasimov's rocket has been developed, and

Mr. Gerasimov, rather than the Commission, must give the directions for its development. Since when manufacturing rocket propellant and smoky powder at different times compounds differing somewhat in their properties can be obtained, the compounds requested by Mr. Gerasimov in his report should be ordered for all 100 rockets. The Commission should add that an order of powder for 15 rockets has already been given to the French Sevran Livry plant.

The Manager of Artillery Engineering Institutions should communicate the need for manufacture at the Shostka Gunpowder Plant of powder and propellant for 100 casings, as follows:

Forty pud [1440 lb] granulated rocket propellant (the grains to be of the same size as in smoky rifle powder), 10 pud [360 lb] black powder, the 52/18/30 compound used for French mining powder, and 3 pud [108 lb] of 62/18/30 powder; the whole to be delivered, if possible, to the Okhtensk Gunpowder Plant by the middle of August, this year.

Furthermore, it is necessary to continue, if possible, experiments on the pressing of this powder into cylinders for rockets, in accord with Mr. Gerasimov's instructions, on the presses of the molding workshop of the Okhtensk Gunpowder Plant, during the same time period.

In accord with Mr. Gerasimov's instructions, the gun factory should be requested to ship its remaining adaptable rocket fuses to the Obukhov Plant, and to adjust the instrument for determination of the rockets' gyroscopic properties.

It would be useful to bring this journal of the Commission to the attention of the Navy Department.

15. THE ROTATING ROCKET DESIGN OF RETIRED LIEUTENANT VOLOVSKII*

In the Artillery Committee Journal No. 629 (1912), a memorandum of Lieutenant Volovskii, now retired, former Vice-Director of the Putilov Factory, dated 19 April of this year, and submitted to the Secretary of War, was discussed. This memorandum contained proposals relating to Volovskii's design for a rotating rocket to be fired at troops and airplanes. On the basis of both experimental data and literature on the subject (analyzed in detail in this journal) the Committee has concluded that the performance of any experiments whatsoever with this rocket — bearing in mind a number of proposed experiments with more highly-developed rocket designs — is not of such interest as to justify the financial outlay they would require. In this journal the Head of the Chief Artillery Administration proposed the following resolution: "The idea of using rockets as anti-aircraft weapons is new, and experiments should therefore be made on Volovskii's rockets, regardless of the financial outlay they entail."

When this matter was presented to the assistant of the Secretary of War on 9 June of this year, an order was given to inquire of Mr. Volovskii the cost of manufacturing 10 of his rockets, and then to conduct firing experiments

* Artillery Committee Journal No. 1254, 8 November 1912. AIM Archive, Artillery Committee store, entry 39/3, file 704, sheets 241—243.

on them, jointly with the aeronautical section, with the object of determining the effect of their bursting in mid-air upon aerial targets.

Mr. Volovskii was informed of the proceedings by Directive No. 26681 of the Chief Artillery Administration, for 18 June of this year. In reply he again submitted, on 13 October, a memorandum with appendices, addressed to the Secretary of War, and this, in a note No. 1936 of the business manager of the Artillery Committee (1912), was referred to the Committee for its conclusion.

In the copy submitted Mr. Volovskii notes that since the presentation of his initial design for a rotating rocket, he has made essential improvements in the rocket, and that the design of individual component parts of the rocket has undergone detailed elaboration.

In the original design (see sketch No. 1)* the union of the rocket main body with the tail was to be by means of a common metal tube containing three radial fins at a small angle to the axis of the tube. When the rocket was launched, the pressure of the exhaust gases on these fins was to impart to the rocket not only translational, but also rotational motion. Such an arrangement, in the inventor's opinion, with the force of the gases working simultaneously to create translational and rotational motion, would operate to the detriment of the former. To overcome the deficiency, in rocket No. 2, the function of the gases was divided into two independent categories by fixing inside the casing and concentric with it a second tube of smaller diameter, constituting the rocket tail. The tubes were joined by four tie-rods, arranged at a certain small angle to the axis of the rocket, so that the cross section of the rocket would be divided into two fields, a central one, inside, for passage of the gases creating the translational motion, and an external annular one for passage of the gases along four channels to give the rocket rotational motion. Division of the cross-sectional area of the rocket into two fields made it possible to change the rotational velocity of the rocket by altering the angle of inclination of the tie-rods, and to determine the most efficient ratio of the areas of the central and external annular fields by varying the diameter of the internal tube, thus regulating the partition of the gases between translational motion and rotation.

Rocket type No. 3 is designed for grazing fire from airplanes against cavalry. The internal tube is replaced in this rocket by a wooden rod, which must be covered with a layer of pitch or resined hemp. During flight the resin must be ignited, which will cause it to emit a great quantity of thick black smoke. The descent of such a burning object, with a great quantity of smoke, upon the cavalry will, in Mr. Volovskii's opinion, throw the horses into a state of panic fear, while the projectile in the rocket's warhead, carrying a powerful explosive, will upon impact complete the total disorder of the cavalry.

To the sketches of the rockets are appended those of:

a) a launching device (rocket cannon) with control panel showing that the contacts on the rocket head touch those on the launcher;

b) a maneuverable gun-carriage; and

c) a rocket mitrailleuse.

The design of these is evident from the sketches attached to the copy.

With regard to the Chief Artillery Administration proposal that 10 rockets of Volovskii's design be built and presented for testing, Volovskii reports

* See Figure 34 on p. 143.

that all his efforts to have this done in private plants have come to nothing, since none of the plants have ever engaged in rocket production, and would therefore have to install a new plant before being able to undertake it.

The inventor was invited to a session of Section V of the Committee on 30 October of this year, so that he might personally elucidate several points. Meanwhile, he had reported that if he were vouchsafed a sum of 1000 rubles, 100 rockets of his design might be ordered even from a private plant, and could then be presented to the Artillery Department for testing.

Opinion of the Committee. Mr. Volovskii's new design for a rotating rocket is distinguished from the previous one by the installation of a tube in the path of the exhaust gases. This tube is intended for passage of a part of the gases, communicating exclusively translational motion to the rocket, while oblique tie-rods are placed in the external annular space formed, to set the rocket in rotation.

The designation of these rockets as anti-aircraft weapons cannot be called correct. The general principles established for anti-aircraft fire, i.e., the longest possible range, accuracy, and rapid fire, are beyond any doubt more readily to be attained by the special guns now being designed for this purpose, and are almost completely lacking both in rockets of established type, or in those identical to them, such as the rocket proposed by Mr. Volovskii.

In confirmation of the above the Artillery Committee Journal No. 277, for 1909, on the results of experimental firing upon dirigibles, conducted near the town of Sestroretsk, should be quoted: "The idea of bombarding balloons with rockets had to be completely dismissed, due to the notorious aimlessness of this bombardment, which was revealed by the experiments; due to the slowness and poor accuracy of the rockets, one could not count on throwing a rocket anywhere near the dirigibles, if the latter were to move."

Although the modifications noted above in Mr. Volovskii's rocket do not appear essentially to affect his former design or to overcome the deficiencies of this type of rocket, as noted in the Artillery Committee Journal No. 629 for 1912 (lengthened casing instead of a tail; cfr. experiments with Colonel Sazanov's rocket; communication of rotational motion during the translational motion), so that there are no adequate grounds for expecting from it any increase in range or accuracy over the rockets of old design still in use, the Artillery Committee finds it possible, in view of the recent interest in finding the most perfect type of rocket, to meet the inventor half-way and give him an opportunity for experimental verification of his calculations. With this object the Committee feels that Mr. Volovskii should be allowed the sum of 1000 rubles to order 100 rockets of his design from a private plant, so that upon their completion, he can present these rockets, with a stand, to the Chief Artillery Administration for testing of their flight accuracy and range.

16. REPORT ON THE EXPERIMENTS WITH MAJOR-GENERAL SAZANOV'S ROCKETS*

At the instance of a directive of the Chief Artillery Administration, No. 9599, for 26 February 1913, 20 rockets of Major-General Sazanov's

* TsGVIA, store 504, entry 8, file 1473, sheets 10—17.

design were manufactured in the rocket workshop, and filled with a black powder propellant, for the conduct of experiments to determine their range, the bursting altitude of the cap, and the degree of illumination of terrain they provided. The experiments on these rockets were begun at the former Nikolaev Rocket Plant and consisted of the following: an iron riveted 3" casing without base plate, 34 3/4" in length, with walls 0.08" thick, was filled with rocket propellant; a cap filled with sand equal in weight to the luminous pellets was seated on it, and the rockets put together in this way, after being fitted with two parallel lateral tails, were launched from a stand to determine their range and accuracy.

The journal of these launchings, appended to the report of the assistant to the Head of the Nikolaev Rocket Plant, No. 7, for 4 May 1909, shows that in the launchings of six rockets, ranges between 3100 and 3420 paces were obtained, with deviations from the directrix ranging from 0 to 300 paces. For increase of the range it was then proposed to press into the casings a black powder propellant; experiments on the pit burnout of rockets with a 39" channel had shown the iron casings to be sufficiently strong for this propellant. To complete the experiments it thus remained only to equip the casings with black powder propellant and the caps with luminous pellets, and to launch the rockets from the stand, to determine their range, the thickness of the blind propellant (bursting altitude of the cap), and the degree of illumination of the terrain.

The features of Major-General Sazanov's rockets are the following: 1) the lack of a base plate; 2) a long, narrow cap for the luminous pellets; 3) two tails located along two generatrices of the casing, rather than one, located along an extension of the rocket axis; 4) the absence of a fill of chalk and sulfur; 5) a time-fuse is screwed into the plug of the finished rocket; 6) the cap, also finished and filled with pellets, is screwed into the same plug.

Major-General Sazanov's rockets have important advantages over existing 3" rocket flares as far as the simplicity of working with them and their improved safety are concerned: 1) in existing rockets with an iron base plate the pressing in of the propellant proceeds from the head end, and in order to form a chamber the first fills are of chalk, which is taken out after the entire casing is filled. In Major-General Sazanov's rocket, thanks to the absence of a base plate, the casing can be filled from the tail end, and in order to form the chamber, it need proceed no further than a point the necessary 1 1/2" away from the cutoff of the casing. The chalk fill is thus superfluous, as a result of which the rather dangerous operation of scraping the chalk out of the filled rocket with steel hooks can be eliminated. 2) In existing rockets the time-fuse, having first been filled with propellant throughout its length, is pressed into the casing by means of the sulfur which at the same time serves as a plug, then the superfluous propellant is drilled out of the fuse, the cap is seated and filled with pellets; in Major-General Sazanov's rockets an iron plug is inserted instead of the sulfur, and the time-fuse and finished cap, complete with pellets, are screwed into this plug.

Major-General Sazanov's propellant-filled casing is thus involved in none of the operations; the fuse and cap are screwed into it in finished form. After rockets had been prepared in accord with the description and sketches provided by Major-General Sazanov, experimental launchings were begun.

The first rocket, so that its range and lateral deviation could be determined precisely, was launched during the day, and a range of 1265 sagenes [2950 yd] was obtained, with a deviation of 100 sagenes [235 yd] to the right. The height of the explosion and the degree of illumination could not be observed, since the daylight and the great range made the bursting of the cap and the combustion of the pellets invisible. When the next rocket was launched, in the evening, it burst on the stand after ignition; it tore off the cover of the stand, fell near it and burned relatively slowly, throwing out of the burst in the casing pieces of propellant burning in the air. The burst in the casing was about 10" in length, in the head part, partly along a seam, and partly in a weldless section; the cap was thrown out and burst separately from the casing, a short while later. After construction of a new stand, a rocket was launched in the presence of Major-General Sazanov, who had been invited, and the same thing happened: the casing burst in two places, and the bursts, about 12" long in the head part, and some 15" in the tail part, occurred partly along seams, and partly in weldless areas. After this it was decided to test the rocket by on-the-spot burnout in a pit, but without determination of the gas pressure, since there was some apprehension as to the adequacy of the instrument for pressure determination. This turned out to be fully justified, since the burned out rocket burst and the stand to which the manometer is normally attached was torn from its place by the force of the gases. The head section of the casing suffered a 12" burst along the seam. When a channel was drilled in the propellant of one of the rockets, the propellant took fire and the casing suffered a 20" split in a weldless place in its longitudinal middle. Somewhat later rockets whose ignition channel 0.787" in diameter was bored out (in two rockets) to 1", and later, in one rocket, to 1.5", were burned in the pit.

All of the rockets burst in the pit, accompanied by phenomena more characteristic of an explosion than before: a sound like a shot, and extensive damage to the casing.

The direct reason for the failure of the experiments on Major-General Sazanov's rocket may be the following. In both cases of bursting, it occurred while the rocket was being placed on the launching stand immediately after its ignition. If the data of Table 1, characterizing the conditions of ignition and initial combustion of the propellant in Major-General Sazanov's rockets are compared with those for the 3" rocket flares currently being mass-produced and for Colonel Ennatskii's No. 2 rocket, we see that while the two latter rockets each have 4 sq in of combustion surface per unit of ignition channel volume, Major-General Sazanov's rocket has 5.1 sq in. The gunpowder propellant with which his rocket was filled therefore exceeded conventional rocket propellant in power by a factor of at least 1.4.

Together all this shows that at every given moment of combustion of the propellant, a considerably greater amount of gas per unit of volume is developed in the channel of Major-General Sazanov's rocket than in the others with which it is compared. Furthermore, the special shape of this channel must be taken into account, since it is twice as long as in the other rockets, and smaller in diameter, i.e., it has the form of a very long, narrow tube, which makes outflow of the liberated gases at the proper time far more difficult.

TABLE 1

Parameters of rocket	3" mass-produced	3" No. 2 of Colonel Ennatskii	3" of Major-General Sazanov
Channel			
Length.	15 in	15½ in	30 in
Diameter	5 in	1 in	0.787 in
Ratio of diameter to length	0.066	0.065	0.026
Surface	47.12 sq in	48.70 sq in	74.17 sq in
Volume	11.78 cu in	12.18 cu in	14.58 cu in
Ratio of surface to channel volume	4 sq in	4 sq in	5.1 sq in
Propellant			
Type of propellant . .	Rocket	Rocket	Gunpowder
Density	1.78	1.78	1.85
Force	1.00	1.00	1.40

These data, together with the fact that in every case the rocket burst immediately after its ignition, give a basis for supposing that the bursting occurred through the above-mentioned structural deficiencies in the shape of the channel and the unsuitability of its dimensions to the force of the propellant used.

The favorable results of the experiments conducted with this rocket in Nikolaev, with a channel of exactly the same design, are wholly explained by the weakness of the propellant manufactured in the Nikolaev Rocket Plant, some idea of which will be given by the following considerations.

All other things being equal, an idea of the force of the rocket propellant can be gained from the range over which it propels the rocket. The average range of a 3" rocket at the Nikolaev Rocket Plant was 450 sagenes [1050 yd]; at the Shostka plant, because of the superior rocket propellant, it reached 580 sagenes [1355 yd]. Later, during the pit burnout experiment on a 3" rocket filled with gunpowder propellant, performed at the latter factory, it was revealed that both the magnitudes of the separate pressures of the gunpowder gases against the head part of the rocket, and the total work area bounded by the curve of these pressures exceeded the very same parameters, as obtained for rockets filled with the propellant of the Nikolaev Rocket Plant, by approximately 40 %. These data, taken together, indicate that the power of the Shostka plant's propellant exceeded that of the Nikolaev plant's by a factor of about 1.80. Despite its roughness, this estimate gives an idea of the very serious difference in the power of the propellants used in both cases in the experiments on Major-General Sazanov's rockets.

To preclude the possibility of the rocket's bursting, the elasticity of the gases developed in its channel must be reduced, and this is most simply done by reducing the force of the rocket propellant.

Choice of a suitable weaker propellant, or shortening of the rocket's ignition will yield the desired result, but with a corresponding reduction in the rocket's serviceability.

In order to reveal, insofar as present circumstances permit, the ballistic qualities of Major-General Sazanov's rocket, we shall compare it with mass-produced 3" rocket flares and with Colonel Ennatskii's No. 2 rocket, assuming, as was shown in experiments conducted at the Nikolaev Rocket Plant, that it is capable of transporting its luminous payload (pellets), weighing 16 pounds and 8 zolotniki [16.08 pounds], a distance of 1100 sagenes [2575 yd].

The major task laid by present service requirements upon rocket flares is the transport of the greatest possible luminous payload over the greatest possible range in a given direction. Through its fundamental design principles the rocket incorporates in itself both the payload and the means for its transport.

If we designate the weight of the luminous payload as C, and the distance it can be transported as S, the product CS is an approximate indication of the rocket's useful work. The same amount of useful work, however, can be obtained by various means, depending on the design of the rocket, and the most perfect design will be that which allows production of the given amount of useful work at minimum cost. If we deduct C from the total weight of the rocket readied for launching P, we obtain the weight of the driving load D, whose sole function is to transport C. From this it is clear that the ratio of the product CS, the useful work of any rocket, to the weight D of its driving load,

$$R = \frac{CS}{D} = \frac{(P-D)\,S}{D},$$

shows how much useful work is obtained per unit of driving load, and gives an accurate idea of the value of the rocket's design.

The following comparative table gives estimates of the amount of useful work and design coefficients for three rockets, the range S of Major-General Sazanov's rocket being taken as that obtained during experiments at the Nikolaev plant.

This table shows that the amount of useful work (CS) of Sazanov's rocket is twice that of the mass-produced rocket and 1.7 times that of Colonel Ennatskii's No. 2 rocket. When the design coefficients are compared, the results are not so pronouncedly in favor of Major-General Sazanov's rocket, but it still retains its pre-eminence. Let us now see to what this is due.

The following table shows that Major-General Sazanov's rocket has a long, narrow cap, promoting the streamline flow of air about it, and a considerable cross-sectional load, but that it is filled with a somewhat weaker propellant.

Going by the value of the construction coefficient, Colonel Ennatskii's rocket has the single advantage of the narrow cap, while the least successful design of the mass-produced rocket possesses none of the indicated advantages.

In order to determine the influence of the shape of the cap on the range of a rocket, four mass-produced rockets whose wide caps ($d = 6"$) had been replaced, retaining the same weight of luminous payload C, by narrow

ones ($d = 4''$), were launched. The range obtained varied from 780 to 850 sagenes [1820 to 1985 yd], showing that the wide cap reduces the range of a mass-produced rocket by no less than 200 sagenes [465 yd].

TABLE 2

Parameters of rocket	3" mass-produced		3" No. 2 rocket of Colonel Ennatskii		3" of Major-General Sazanov	
	Pounds	Zolotniki	Pounds	Zolotniki	Pounds	Zolotniki
a) Load						
1) Luminous C pellets .	14	16	10	18	16	8
2) Driving D						
Propellant	9	51	9	20	17	18
Empty casing . . .	6	44	6	28	10	26
Sulfur	1	48	2	12	10	26
Cap (empty) . . .	3	32	2	78	3	86
Tail	3	93	2	48	5	84
					2 tails	
Totals	24	76	22	90	37	22
b) Range S	580 sagenes [1 sagene = 7 ft]		1000 sagenes [1 sagene = 7 ft]		1100 sagenes [1 sagene = 7 ft]	
Useful work CS	8210 pound-sagenes [1 pound-sagene = app. 7 ft-lb]		10160 pound-sagenes [1 pound-sagene = app. 7 ft-lb]		17688 pound-sagenes [1 pound-sagene = app. 7 ft-lb]	
Useful work per unit of driving load: $R = \frac{CS}{D}$ (design coefficient)	331.7 pound-sagenes [1 pound-sagene = app. 7 ft-lb]		443.6 pound-sagenes [1 pound-sagene = app. 7 ft-lb]		475.2 pound-sagenes [1 pound-sagene = app. 7 ft-lb]	

TABLE 3

Parameters of rocket	3" rocket flares		
	mass-produced	Colonel Ennatskii's No. 2	Major-General Sazanov's
1) Shape of cap:	Wide	Narrow	Narrow
Diameter	6 1/4 in	4 in	4 3/4 in
Length	12 1/4 in	19 1/2 in	21 1/4 in
2) Cross-sectional load .	1.39 pounds	1.11 pounds	1.81 pounds
3) Force of propellant:			
Short	Rocket (Shostensk)	Rocket (Shostensk)	Rocket (Shostensk)
Relative force . .	1	1	0.77
4) Design coefficient .	331.7 pound-sagenes	443.6 pound-sagenes	475.2 pound-sagenes

Table 4 shows that when the mass-produced rocket and Colonel Ennatskii's No. 2 are both given a narrow cap, they have the same design coefficients, understandably, since in this case their designs are almost identical.

In this case General Sazanov's rocket differs from these in the great length of its casing and the consequently greater transverse load,

TABLE 4. Design coefficients of rockets

	3" rocket flares: mass-produced	Colonel Ennatskii's No. 2	General Sazanov's
1) Actually	331.7 pound-sagenes	443.6 pound-sagenes	475.2 pound-sagenes
2) When the wide cap of the mass-produced rocket is replaced by a narrow one. . . .	446.0 pound-sagenes	443.6 pound-sagenes	475.2 pound-sagenes

as well as in the absence of a base plate. Whether the superior design coefficient of General Sazanov's rocket is to be attributed only to its transverse load, or whether ballistic advantages resulting from the absence of a base plate also play a role are questions which can be answered only after careful experimentation. In any case, it should be recognized that even going by the results of the tests conducted at the Nikolaev plant General Sazanov's rocket is distinguished from the other rockets compared with it by its ballistic properties, and in addition has the important advantage over them of its greater simplicity and the safety of its equipment.

In order to show how such a feature as the absence of a base plate can be reflected in the useful work of a rocket's driving load, let us consider the conditions under which the working pressure necessary for motion is created in its channel.

The gases formed by combustion of the propellant act equally in all directions. Their pressure on the sides of the casing is balanced, but that on the head part has nothing to balance it, since the gases can leave through the orifices in the base plate; this pressure is what causes the axis of the rocket to move in the direction opposite to that of the outflowing gases. From this it is evident that the motion of a rocket proceeds from the principle of reaction or recoil, which also takes place in a fire-arm. But there is no recoil when the fire is blank; for it to occur, the gases liberated by combustion of the charge must create an impact by means of a bullet or projectile.

In exactly the same way creation of a working pressure in the channel of the rocket requires the placing of some obstacle in the path of the liberated gases to reduce their velocity. Then the schematically required working pressure p will be obtained from the difference $V-V_1$ between the speed of formation of the gases by combustion of the propellant and the speed of their outflow through the open end of the casing.

This obstacle, reducing the initial velocity of the gases at the end of the casing, is provided by the base plate, in the wide sense of the word. When $V=V_1$, this difference, and therefore the propulsive pressure, go to 0.

Experiment shows that if we make no channel at all in a rocket of conventional design, or fill it with a compound of light brown powder, i.e., create such conditions that the very slowly liberated gases from combustion of the propellant will find a completely free exit through the hole in the base plate, such a rocket will not move from the stand because of the absence of any working pressure. From what has been said it is not hard to see that the same pressure p can be obtained from a very great number of values of

the velocities V and V_1, or from widely differing consumptions of rocket propellant. The designer's problem is to choose such values that the consumption of propellant, as well as the driving load D, will be minimum. For a given p, however, the minimum speed of combustion (consumption) of the propellant can also be obtained for a minimum V_1. From this the enormously important role of the base plate in rocket design is evident.

In general the gases obtained from combustion of the propellant, in passing to the casing outlet, lose a part of their initial velocity due to friction against the walls of the channel and of the casing, and, as might be expected, of the internal partial pressure as a result of which some difference in the velocities V and V_1 and the corresponding pressure are created as it were naturally.

With the object of decreasing further V_1, the exhaust velocity of the gases, obstacles increasing their friction must be placed in their path, or they should even be made to do some work, e. g. :

1) Keeping the rocket caliber the same, the lengths of the casing and the ignition channel are considerably increased (rockets of Sazanov and Volovskii).

2) The area of the free orifice in the casing is reduced by a small flange, and the remaining orifice is covered by a disk of cardboard (German rocket flares Mark 78 and 8 cm. Guards' Captain Ennatskii's report on his foreign mission of 1909).

3) A base plate with holes whose area depends on the circumstances is attached to the free end of the casing (majority of present and past systems).

4) The exhaust gases are made to turn a propeller attached to the rocket and serving to make it rotate in flight (English 9- and 20-lb military rockets. Ennatskii's report on his foreign mission of 1909).

From what has been said it follows that the longer the rocket (channel), the less it requires a base plate (in the narrow sense of the word). Consequently, a length is conceivable at which the need for a base plate will disappear altogether. This, or something close to it, is the case of General Sazanov's rocket. The following facts convince us of this:

1) The very great length and small diameter of the channel of Sazanov's rocket. With the same caliber it is more than twice as long as comparable rockets.

2) The high value of the design coefficient of this rocket, whereas when the base plate is inadequate (its total absence, as already shown, is not permissible), the required driving pressure is obtained by excessive consumption of rocket propellant, completely uncalled for by the circumstances, which cannot fail to be seriously reflected in the value of the driving load D, and therefore in the coefficient itself.

3) The complete failure of experiments on the application of the principle of large holes in the base plate to the 3" mass-produced rocket with its short channel.

All of this brings us to the unavoidable logical conclusion that General Sazanov's rocket, like all rockets, has a base plate, whose role is filled by the great length, and in part, by the narrowness, of its channel.

The last peculiarity of General Sazanov's rocket is its being guided by two completely identical lateral wooden tails.

The simplest method of guiding the motion of a rocket is by continuation of the rocket casing in the direction opposite to the motion, by means of a

rigid tail. The basic requirements the tail must satisfy in order best to fulfill its function are:

1) The axis of the tail must as far as possible be an extension of the axis of the rocket casing.

2) The tail must be an immutable system.

3) It must be as light as possible, in order not to increase the driving load *D* and not to shift the rocket's center of gravity in the direction of the tail. The tails of General Sazanov's rocket have an insufficiently large cross section for their length, and the means of attaching them to the casing does not assure their perfect parallelism. The relative position of the tails therefore is slightly affected by random occurrences, or by the weather. Under such circumstances one cannot even discuss satisfaction of conditions 1 and 2 above with any sort of precision.

TABLE 5

Parameters of the rocket	3" rocket flares: mass-produced	Colonel Ennatskii's No. 2	General Sazanov's
Length of casing . . .	23 in	21.6 in	34.75 in
Length of channel . . .	15 in	15 in	30 in
Diameter of channel . .	1 in	1 in	0.787 in
Weight of rocket . . .	39 pounds	31 pounds	1 pud [36 pounds] 14 pounds
Weight of tails. . . .	3 pounds 93 zolotniki	2 pounds 48 zolotniki	5 pounds 84.3 zolotniki (two tails)
Weight of tail as a percentage of weight of rocket	10%	7%	11%

Despite their clearly inadequate thickness, together, as Table 5 shows, they nonetheless are heavier than each of the tails of the other rockets, and in particular, of Colonel Ennatskii's rocket No. 2. Furthermore, attached to the sides, rather than beneath the casing, they undoubtedly create extra air resistance, which cannot fail to have an adverse effect on the range. Altogether, one can only term this arrangement of tails extremely negative and deplore its use by General Sazanov, since the good ballistic qualities of his rockets must suffer from it, to a greater or lesser degree. This is the more lamentable since for such rockets (lacking a base plate) there exists a tested system which fulfills its objective, of conventional central tails, located along the rocket axis, attached to the casing by means of an iron bracket.

Experiments on the application of two lateral tails to rockets were performed in Russia after the Sevastopol campaign (Major-General Konstantinov's work on rockets), and the idea was rejected even then.

The preceding analysis of General Sazanov's proposal permits the following practical conclusions.

The most important part of his idea is the problem of a long, narrow rocket, with a long, narrow channel. General Sazanov has doubled the

15" channel length hitherto accepted for a 3" rocket flare, and has equipped this lengthened rocket with a similarly narrow cap to hold the pellets. As a result of all this the rocket's load is distributed for the most part longitudinally.

This shape has promoted easier streamline flow about the rocket in motion and, in addition, has greatly increased its cross-sectional load. These factors in turn have promoted increased range, and consequent increase in the rocket's design coefficient.

The great length of the rocket's ignition channel has made a base plate (in the narrow sense of the word) superfluous, and has made it possible to profit from the resulting advantages of convenience and safety.

Finally, the rocket proposed by General Sazanov, despite its clearly unsatisfactory guidance system, surpasses Colonel Ennatskii's No. 2, the best of the rockets compared with it, in the value of its design coefficient, and in addition has on its side all the advantages resulting from the absence of a base plate.

The advantages cited for a long rocket and channel are so significant as to demand the attention of rocket designers, especially when 3" or similar calibers are involved.

Major-General Rudakov, assistant to the Head of the Percussion-Cap Plant

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NAME INDEX

EXPLANATORY LIST OF ABBREVIATED NAMES OF USSR INSTITUTIONS APPEARING IN THIS TEXT

Abbreviation	Full name (transliterated)	Translation
AIM	Artilleriiskii Istoricheskii Muzei	Historical Artillery Museum
GAU	Glavnoe Arkhivnoe Upravlenie	Main Administration of Archives
MGU	Moskovskii Gosudarstvennyi Universitet	Moscow State University
MVTU	Moskovskoe Vysshee Tekhnicheskoe Uchilishche (im N. E. Baumana)	Moscow Higher Technical School (im. N. E. Bauman)
TsGAOR	Tsentral'nyi Gosudarstvennyi Arkhiv Oktyabr'skoi Revolyutsii i Sotsialisticheskogo Stroitel'stva	Central Government Archives of the October Revolution and of the Building of Socialism
TsGAVMF	Tsentral'nyi Gosudarstvennyi Arkhiv Voenno-Morskogo Flota	Central Government Archives of the Navy
TsGVIA	Tsentral'nyi Gosudarstvennyi Voenno-Istoricheskii Arkhiv	Central Government Archives of Military History
VUK	Voenno-Uchenyi Komitet	Military Scientific Council

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